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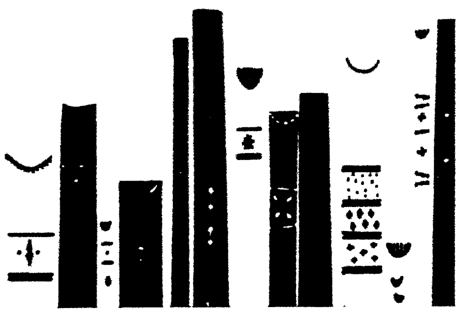

A Bibliography

CRUSHING AND GRINDING

1960

CHEMICAL PUBLISHING CO., INC.

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FOREWORD

In 1951 the Department of Scientific and Industrial Research published a 'Bibliography on Industrial Drying' which attracted considerable attention and became widely distributed. The success of this venture suggested that bibliographies on other unit operations would be worth while and it was also considered that the preparation of such bibliographies would be a small contribution towards filling one of the gaps referred to in the Report of the Committee on Chemical Engineering Research (H.M.S.O., 1951)—the collection and interpretation of research information.

After consultation between the Department of Scientific and Industrial Research and the Institution of Chemical Engineers it was agreed that 'Crushing and Grinding' would be a good subject to start with. This choice was influenced by the fact that a very wide range of industries use crushing and grinding in their operations and that few recent textbooks on the subject existed. It was desired to introduce a selective and critical element, and with this aim in mind a small committee to advise on the planning of the work was appointed in July 1953 with the following membership:

A. S. White Esq., B.Sc., F.R.I.C., M.I.Chem.E. *Chairman*	Head of Chemical Engineering Division, Atomic Energy Research Establishment, Harwell.
J. C. Farrant Esq., M.I.Chem.E., M.A.I.M.E.	Formerly of International Combustion Products Ltd.
A. T. Green Esq., O.B.E., D.Sc., F.R.I.C., F.Inst.P., Hon.M.Inst. Gas E., M.I.Chem.E., F.Inst.F., F.I.Ceram.	Director of Research, British Ceramic Research Association.
H. Heywood Esq., D.Sc.(Eng.), Ph.D., M.I.Mech.E., M.I.Chem.E., M.Inst.F.	Principal, Woolwich Polytechnic, formerly Imperial College of Science and Technology, University of London.
J. W. Meredith Esq., M.I.Struct.E., M.I.Chem.E., A.I.Min.E.	Managing Director, Huntington, Heberlein & Co., Ltd.
C. J. Stairmand Esq., B.Sc., M.I.Chem.E., A.Inst.P.	Imperial Chemical Industries, Ltd, Billingham Division.
W. E. Sharples Esq., M.I.Mech.E., A.M.I.Chem.E.	Formerly Chief Engineer, Fisons Ltd.
P. F. Whelan Esq., D.Sc., F.R.I.C., M.I.M.M., M.I.Chem.E.	Consolidated Tin Smelters Ltd, formerly Head of Coal Preparation Research, National Coal Board.
R. Ashton Esq., M.A., B.Sc., F.R.I.C.	Information Division, Department of Scientific and Industrial Research.
W. H. Bickle Esq., B.Sc., A.R.I.C.	Information Division, Department of Scientific and Industrial Research.

The publication is now presented in two parts: the first contains a series of short reviews and the second the classified bibliography.

The Committee wishes to express its indebtedness to the authors of the short reviews.

The task has been largely a part-time one and the bulk of the work has fallen on Mr W. H. Bickle, to whom the Committee is much indebted. Sincere thanks are also due to the many individuals and organizations which have helped by allowing access to their records and by specialist advice.

A. S. WHITE
Chairman of Committee

COMPILER'S NOTE

THE bibliography consists of some 2800 literature references, accompanied by abstracts or annotations, derived mostly by direct reference to original papers, and from abstracts by competent authorities; these are classified under the headings shown in the contents list. Even though some ambiguity may exist in the allocation to the various classes, especially in the theoretical section, in planning the work a breakdown of some kind was found necessary for convenience of handling and search. Cross-references have been reduced to a minimum by resort to a small amount of duplication. The contents of the classified bibliography of 127 abstracts on the theory and practice of coal grinding, compiled by Dr H. Heywood for the Combustion Appliance Makers Association (C.A.M.A. Document No. 1657, 1938), have been incorporated in the present volume by kind permission of the Director-General of the British Coal Utilization Research Association. Two sections on methods of particle-size and surface-area determination and on certain aspects of classification have been incorporated. These two subjects could be regarded as separate subjects in their own right and therefore meriting their own bibliographies, but it was thought appropriate to include a selection of references in the present work.

Entries are in alphabetical order of authors' names in each subsection, except for anonymous papers which as far as possible are in alphabetical order of titles of periodicals. Abbreviated titles of publications conform to the *World List of Scientific Periodicals*, 1900–50, 3rd Edition, 1952, Butterworth.

['**P**'] at the end of an entry indicates that mill performance data have been presented in the paper concerned.

Thanks are due to the Director of the British Ceramic Research Association for providing copies of some hundreds of entries from the Association's own comprehensive card index; to the Director of the Research Association of British Paint, Colour and Varnish Manufacturers for access to the Association's card index; and to Dr Heywood for the loan of his cards.

W. H. BICKLE

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SHORT REVIEWS

BIBLIOGRAPHY

Fundamental Aspects of Crushing and Grinding

W. H. Bickle, B.Sc., A.R.I.C.
(*Department of Scientific and Industrial Research*)

Crushing and grinding, or comminution, form one of a series of operations, sometimes known as 'unit operations', which are used over a large range of industries. Some of these operations, such as distillation or drying, are supported on substantial theoretical foundations which provide a satisfactory if not always complete understanding of the operation, and which also provide a basis for design, for prediction of results and for a standard of achievement. Crushing and grinding processes have no such foundations. Originally laborious manual operations they advanced to the mechanical stage of pan and stamp milling and progressed subsequently by way of ingenious design of machinery and improvement of process on empirical grounds; theoretical aspects of design have contributed to this advance but the fundamental aspects of breakage are still inadequately understood. Consequently there is no real theoretical basis by which a target of performance can be set, unless the target is so remote as to be almost out of sight. For instance, in a particular drying operation, performance data may show that 40 per cent or 100 per cent more energy is being used than is theoretically necessary for removal of the moisture. Similar data from a grinding or crushing operation would show that from 100 to 1000 times more energy is being used than should be necessary on theoretical grounds. In the former case the reasons for the apparent waste of energy can be accurately assessed and the way to improvement closely defined. With the latter, no valid reasons for excess energy consumption have been agreed and improvement in operation is therefore based mainly on empiricism.

An extended theoretical study of comminution was begun in the early 1920's by Martin in England, also by Gaudin and later J. Gross and others in the U.S.A. The results of these and subsequent attempts to provide the subject with a theoretical basis were summarized by J. Gross in 1938 in Bulletin No. 402 of the U.S. Bureau of Mines. He pointed out that although crushing and grinding machinery had been brought to a high standard of development mechanically, corresponding advances in theory had not been made, and that the reason for this lack of advance was due largely to the unfortunate situation arising from the Rittinger–Kick controversy. This controversy, before and since that time, has been concerned with the validity of one or other of two hypotheses, (a) that of Rittinger (1867)*, which maintains that the energy of comminution is proportional to the new surface produced, that is, proportional to the reduction in linear dimension, and (b) that of Kick (1885), which maintains that this energy is proportional to the reduction in volume or weight of the particle. Although the Rittinger relationship has been and is still found useful by various investigators, it is not considered valid over an extended size range: the experimental evidence in support of it has been severely criticized in that small reduction ratios have been used, the precrushing history of the material has generally

* The numbers placed against authors' names in this review denote the year of publication. See Index for abstract numbers.

been ignored, and the methods used for measuring surface area, particularly the permeability method, have led to doubtful conclusions. Moreover, the net energy input strictly of benefit to the grinding operation has been necessarily calculated as a difference figure, often a minor one, and some of the evidence put forward in support of one or other hypothesis could be held to support either. Since the Kick hypothesis implies that the energy used is absorbed in deformation under tension or compression, it is held by some to be exclusive of the Rittinger hypothesis. By others both hypotheses are regarded as being valid but in separate parts of the size range. For instance von Reytt had observed in 1888 that the surface area increases faster than the linear ratio when the particles are small. Wurker (see Bond, 1951) has recently maintained that although the Rittinger theory appears superficially logical, a real test of its applicability has yet to be satisfield. He claims that the general acceptance of the Rittinger theory has retarded discovery, and that, on the other hand, the strain energy theory is an attempt to find a way out of empirical darkness. More recently, H. E. Rose, in his comprehensive theoretical and practical investigation into ball mill dynamics, has shown that Rittinger's law has no theoretical justification for a ball mill, any straight line obtained being solely due to the conditions of grinding. A summary of the then current position on the two hypotheses was given by Heywood in Document No. 1657, 1938, of the Combustion Appliance Makers' Association, and a detailed appreciation has been presented by Prentice in 1946.

THEORETICAL BASIS OF EFFICIENCY

There has been no lack of endeavour to find out what becomes of the energy used in comminution processes. As early as 1914 Cook had found that of the energy input to a stamp mill, 80 per cent appeared as heat and the remainder is attributed to guide friction, sound vibration, deformation of malleable particles, etc. The low proportion of the total energy input to a mill, found by various operators to be consumed in the actual grinding operation, is typified in the observation of Prentice (1953), that up to 50 per cent of the input energy is dissipated in the prime mover and transmission, while over 80 per cent of the remaining energy is dissipated in the form of heat to the surrounding bodies. Again, on the basis of the data obtained from certain British industries (Hawksley, 1947), it would appear that the power consumption per unit of output is related to the work of transport of the material through the system rather than to the energy requirement for effecting actual size reduction. Carey and Halton (1946) had tabulated the heat balances for various kinds of ball mill, and had found that over 99 per cent of the energy used was dissipated as heat. The loss or waste of energy is even more strikingly indicated by Padszus (1948), who calculated that a quantity of energy as low as 0·001 kWh is theoretically sufficient for reducing 1 kilogramme of iron to a particle size of 1 micron.

Most of the early attempts at fundamental correlation between energy consumption and product characteristics were done on quartz. This material could be obtained as a pure mineral, and a convenient chemical method was at hand for the determination of surface area, this method being peculiarly applicable to quartz. It could be used for the determination of the surface area of particles in the subsieve range, where no other adequate method existed, and where the approximate arithmetical methods then employed led in many cases to errors in surface area calculation very disproportionate to the weight involved in this

range. For the purpose of making the correlation referred to, quartz possessed an advantage among the few solids investigated of having two fairly closely agreeing calculated values for surface energy, that of Edser, 920 ergs/sq. cm, calculated on a physical basis, and that of Fahrenwald, 995 ergs/sq. cm, calculated on a chemical basis. Thus from the newly-exposed surface area of the product as determined experimentally, the corresponding surface energy could be calculated with some degree of confidence and related to the net energy input of the crushed material. For small-scale carefully-controlled ball-milling experiments the net energy consumption was found to be from 100 to 1000 times the calculated surface energy increment appearing in the product, the theoretical efficiencies being thus of the order of 0·1–1·0 per cent. The accuracy of the data from which these values were calculated was limited by experimental difficulties and uncertainties and would account for some lack of agreement in results, but is hardly likely to account for the above low order of efficiency. At this level, improvement in accuracy and in conventional mill design is scarcely likely to improve the order of efficiency.

Improvement in theoretical efficiency values has in fact been obtained by crushing single quartz grains, both by the method of impact and by slow crushing. Modifications have been developed by Kuznetsov (1927), and Kaner (1939), such as the cutting, by impact, of a rock salt specimen. By crushing single particles of crystalline quartz and comparing energy input to the energy of the new surface produced at 980 ergs/sq. cm, Axelson and Piret (1950) obtained efficiencies ranging between 1·7 and 26·5 per cent. With multiple particles crushed under similar conditions, efficiencies did not exceed 1·4 per cent. Under impact conditions Bond and Maxson (1939) obtained up to 60 per cent efficiencies for single particles; Gross and Zimmerley (1928) had obtained values up to 3 per cent for multiple particles crushed by impact. Shearing action has been advanced to account for the low efficiency in crushing a mass of particles, this being assumed to be less efficient than a shattering action; but Carey and Bosanquet (1933) disagree with this view and show that the fracture pattern produced and the energy used are independent of the nature of the load application. Simple pressure, shear action or impact just sufficient to fracture the particles all show similar results. Although this latter assertion is not in accordance with the experience of other workers (Charles (1955) and Meldau (1936)), the simple explanation, that is, of the cushioning effect of smaller particles present, can be regarded as valid, especially as there is direct experimental support for this view by Carey and Stairmand (1952). Attempts have in fact been made to avoid this cushioning effect by design of a 'free crushing' mill, for instance by means of centrifugal ball mills, of which an example is afforded by the design of Carey and Heywood (1941), whose work was not carried to completion, but who regarded the production of a free crushing machine as quite feasible. More recently a free crushing ball and cone mill has been tested by the British Coal Utilization Research Association (1955) and has shown promise of greatly improved performance. If theoretical efficiency can reach as high an order as 26 per cent, it could be assumed that the precise mechanical method of applying the force to the particle, in relation to the shape and size of the particle, may have a profound influence on the efficient utilization of the energy. Such considerations have formed an important aspect of the investigations of Broadbent and Calcott (1955) into mill mechanics, in which connexion the ball and cone mill was designed.

RATE OF STRESS APPLICATION

Whatever the influence of mechanical and manipulative faults in fracture investigations, experimental evidence shows that the energy required for breakage varies greatly with the rate at which the stress is applied. The higher efficiencies, as judged from surface production observed with the slow crushing of single blocks or pieces, are supported by the observation of Heywood (1950–52) that the compression of cubes of a brittle material is a method of fracture involving minimum energy losses. The energy being applied slowly, it is less likely that the limiting strain energy will be exceeded before fracture occurs, than in the method of impact breaking. Evidence on the merits of different procedures is not free from contradiction, for it was shown by Fahrenwald and co-workers (1937), in drop weight tests, that a light high-velocity load does more crushing than an equivalent low-velocity load and produces more fines. Similarly with metal specimens, Koster (1934) found that the amount of energy required to produce fracture decreases with increase in rate of loading. Honig (1937), however, could find no significant difference between the results of pressure crushing and those of impact by falling weight, using cement mortar and brick cubes. Bond (1946) regarded impact strength as a better guide to grinding resistance in gyratory and ball mills than standard crushing strength tests. He tabulated comparisons for 9 materials and the impact strengths of 72 materials. It had been shown by Work (1928), however, that with rapid loads the fines produced are less than those produced by slow compression, the latter being more efficient so far as surface production is concerned. Heywood (1935) and Carey and Bosanquet (1933) found that impact breaking becomes as efficient as slow compression breaking only when the applied impact load is just sufficient to produce fracture. Adams, Johnson and Kwong (1949) also regarded impact breaking (falling weight method) as less economical of energy than breaking by means of a hydraulic press. From experiments with a ball mill and with a 100-ton Amsler machine, Jager (1948) concluded that present methods of comminution could be best improved by progressive crushing and not by impact. The differing effects of impact and slow compression on breakage have therefore led to the postulation of a suddenness factor. Bennett (1941) made a study of the quantitative relations between this factor and the breakage process, and Piret (1953) put forward a rate theory to the effect that resistance to crushing is a function of time. Taylor (1947), in supporting the rate theory, discusses the possibility of viscous flow preceding fracture. Recent work in U.S.A. by Charles (1955) has shown that for a single material, glass in the present investigation, different methods of applying impact load will produce different characteristic particle shapes and different types of size distribution. Although time/load deformation relations have been the subject of extensive investigation for metals (*see* Hopkinson (1872)), there are very few data available for rocks. The view of a rate factor, however, has quantitative support from the work on glass rods by Preston (1942–5), from which it has been found that the breaking stress is inversely proportional to the time of application. (This view is supported by an equation put forward in 1939 for glass and quoted by Preston:

$$\text{Force} \times \log_{10} \text{time}/6 = 65\,000$$

If the curve connecting reciprocal F with $\log t$ is extrapolated substantially each way, two striking implications are made. One is that the stress that can be

supported for an infinitely long time is zero and the other is that no finite stress will cause breakage (of glass) at extremely short time.) Whether these extreme implications are valid or not, the existence of a time factor presents considerable difficulties in the analysis of the energy performance in comminution. The contradictory nature of the conclusions on the merits and effects of impact breaking v. low-velocity crushing may be due to inadequate or faulty data or to the comparatively low velocities used in the falling weight tests. The effects of impact velocities such as those attained in high-speed hammer or pin mills might repay further investigation. Significant results are reported by Puffe (1950) from large-scale tests on lead-bearing sandstone. His replacement of jaw crushers, roll mills and even ball mills by impact crushers has resulted in a substantial increase in the rate of output and a reduction in the power requirements per unit of product, as well as considerable selectivity in the shattering effect.

MECHANISM OF FRACTURE

Since so much of the mechanical energy applied in comminution processes is apparently wasted, a comparison was made by Bond (1953) between the results of mechanical breakage and breaking by explosives. It was found that for equivalent energy input the results were about equal so far as surface production was concerned. This investigation did not solve the problem of what became of the energy, but since it was difficult to believe that the efficiency of shattering by explosive could be as low as 1 per cent or less, it was also difficult to believe that the efficiency of mechanical breakage could be of the low order hitherto calculated.

The great bulk of the energy applied in comminution, however, has been shown by Taplin (1934) to be employed in stressing the particle to the point of fracture, this energy being some thousands of times greater than that necessary for actual fracture, except for very small particles. This means that the work input necessary to break the rock is essentially that necessary to deform the rock beyond the critical strain and form crack tips. Kick (1883) had indicated that the governing factor at the moment of fracture is pressure, but that the quantity of work input is what governs elastic deformation before fracture, the former being in square relation and the latter in cubic relation to the results of fracture. It has since been considered on theoretical grounds and from the results of experiments by Johnson, Axelson and Piret (1949), that the strain energy absorbed is proportional to the new surface produced. Many workers believe that the bulk of the applied energy is used in straining the material and that most of the energy reappears as heat on release of strain. It is claimed by Shand (1954), and disputed by others, that permanent weakening of glass rods can be brought about by prolonged stressing. Some of the energy input thus appears to be absorbed in permanent strain, for attempts at energy balance from the results of calorimeter experiments leave much of the heat otherwise completely unaccounted for. Adams, Johnson and Piret (1949) endeavoured by means of X-rays to discover evidence of such strain in fractured pieces of brittle materials but without success. They found evidence of strain in rock salt, however, but no improvement in the efficiency of grinding which might be expected to result therefrom. Walker and Shaw (1954), on the other hand, consider that evidence does point to plastic flow in materials ordinarily considered brittle. For this reason they consider that little difference exists between ordinary comminution

processes such as ball milling and machine-grinding; they therefore regard it as feasible that the machine-grinding technique offers a precise means of studying the characteristics of various materials, particularly as this technique would provide particles of essentially uniform size. Previously Engelhardt (1947) had considered the relation between energy consumption and surface formation in the products of abrasion, e.g. from grinding wheels, and had attempted a quantitative treatment. Kuznetsov (1954) deals with the distribution of energy by this method and finds that a negligible fraction is spent on increase in surface energy.

The existence of a time interval between application of load and response of the specimen was observed by Andrade (1911) and clearly demonstrated some years later by Clarke and Wood (1949). The nature of delayed yielding in metals and polyamides has been studied by George (1952), who places special emphasis upon the nucleation of macroscopic flow in the region of stress concentration in advance of the primary flow or fracture event. Other work has been done by Wallner (1939), Leeuwerk (1955) and Irwin and Kies (1952). In regarding the mechanism of breakage as a nucleation process, Simmonds (1956) associates breakage with such diverse operations as boiling, dropwise condensation and crystallization, in that they all represent the formation of new interfaces and involve the formation of a nucleus and then a growth process. Investigations on the breakage of glass being conducted at the Massachusetts Institute of Technology, by Charles (1955), Yoda (1956), Smith and Ferguson (1950) (on plastics), facilitated by the employment of a high-speed photographic technique and the use of a device for measuring short impact times, should throw further light on the mechanism of fracture.

The mechanism of breakage has been the subject of considerable investigation, but on a few types of material only, namely metals, glass, concrete, and more recently, coal. The widely accepted view that breakage occurs at, and is facilitated by, cracks and imperfections both outside and inside the specimens has followed the work of Griffiths (1920), who found that glass threads which had aged were much weaker than freshly drawn threads. This is held by Joffe (1928), Smekal (1937) and Andrade (1937) to account for the very low tensile strength of glass as compared with the theoretical strength, the actual strength being several hundred times less than the strength calculated from electrical theory. The depth of surface cracks was found by Holland and Turner (1934) to have a relation to breaking strength, for with cracks at depths no greater than 0·005 mm, they obtained values within 10 per cent of the theoretical tensile strength. Metals exhibit a similar disparity between theoretical and actual tensile strengths, due presumably to inclusions and crystal lattice dislocations, for the recently-prepared single-crystals of various metals have exhibited an enormous increase in tensile strength, up to one hundred times the strengths hitherto accepted for these metals (Hardy, 1955). Timoshenko (1953) has observed that if the strength of brittle materials is affected so much by the presence of imperfections, it seems logical to expect that the value of the ultimate strength will depend upon the size of the specimens and will become smaller with increase of dimensions, since the probability of weak spots occurring is increased. The phenomena connected with fatigue and work hardening of metals would be of interest with regard to the foregoing (Thornton, 1955).

Coal is another brittle material whose chemical and physical nature and lack of homogeneity complicate considerably investigations into the mechanism of

its fracture. Bennett (1941) and Brown (1953) regard the breakage of coal as occurring at flaws which are variable among themselves but which have a random distribution. A general law of coal breakage has been suggested: when work is done on a brittle material, the energy appears partly as new surface of fragmented products and in part as the creation of fresh inner weaknesses. The phenomena and problems concerned with coal breakage are dealt with in a later section.

According to Smekal (1937), the grinding of most bodies is only possible because of minute cracks or faults in the crystal lattice. The distribution of these is such that domains of crystal of the order of a fraction of 1 micron are free from them, so that further subdivision ceases when small pockets of faultless material have been reached. In order to be able to grind still finer, it would, according to this theory, be necessary to produce minute flaws or faults in the lattice within these pockets. One method suggested for producing them is by bombardment with high-energy particles, for instance by X-rays or by thermal neutrons, but no results of any trial on brittle materials have been reported to date.

The relation between actual tensile and theoretical strength has been explored by Sales and Huttig (1954), who regard behaviour on grinding as depending on a 'secondary structure' and associated with the chemical bond strength of the material. From the five methods of structure examination used, they conclude that the grinding process could supply valuable information on structure and bond spectra. Kuznetsov and Kudryashewa (1952) have also investigated the relation between the energy of grinding and the crystal structure or chemical formulae of solids, and have presented data which indicate some correlation. Heywood (1950) has suggested that research is needed into the true meaning of surface to distinguish between new surface due to literal separation of molecules and existing surface present as fine fissures.

A picture of fracture development put forward by Poncelet (1944) was based on the compression of glass squares. A new theory based on thermal agitation and wave propagation is proposed by him to account for the progress, velocity and forking of cracks. The theory accounts for the preferential tendency of the smaller fragments to continue fracturing. It would thereby account for the two distribution modes at first fracture as described by Heywood (1950–52), and illustrated by Andreasen and co-workers (1937) by means of an idealized representation of crack development as judged from observations of crack configurations in crushed cubes of glass and feldspar. Shand (1954) has put forward a concept of the fracture (of glass) based on experimental data: the rate of propagation of cracks originating mainly in surface cracks increases with crack growth until a critical stress is reached at the crack tip at a limiting crack velocity, the critical stress being estimated at up to several million pounds per square inch. In a study of fracture dynamics, Irwin and Kies (1952) found that an extension of fracture requires little driving energy, which may be assessed; a simplified direct application of energy balance principles to rapid fracturing is discussed.

The magnitude of the breaking stress for various solids is found to be seriously modified by the nature of the fluid in contact. Benedicks (1945–8) found that contact with liquids, solutions and certain vapours in some cases increases and in other cases reduces the stress required for fracture as compared with the dry materials. The simple view is that on exposure (of glass) to water vapour, the

entry of the latter into the surface cracks diminishes the cohesion at the crack tip, thus decreasing the surface tension and the breaking strength. When the material is actually wetted, however, the strength may be increased owing possibly to a readjustment, by solution, of the crack surface and a consequent increase in surface tension, or to the behaviour in some respects of the liquid as a solid. Recent work by Gregg (1955) has shown quantitatively how adsorption of water vapour (but not benzene vapour) reduced the breaking strengths of highly compacted discs of calcium carbonate, kaolin and boric acid. The presence of water vapour in the surface cracks of glass is reputed to be partly responsible for the disparity between theoretical and actual tensile strengths. On the other hand Gurney and Pearson (1949) found that contact with water vapour and carbon dioxide both delayed the fracture of glass rods. A comparable effect was found by Bangham (1945), where the plastic deformation of coal was facilitated by the presence of adsorbed water vapour. Brown (1953) found that if the adsorbed water is removed by heating to a moderate temperature, say 130°C, the coal after cooling could be broken more easily than if not thus treated. Eller (1928) and Witte (1931) discovered that the time of grinding cement clinker could be reduced by lowering the relative humidity of the air in contact, and similar results were obtained by Albinsson (1953) for the commercial grinding of feldspar. Investigations, however, on the effects of contact with liquids and vapours possibly cover a variety of phenomena which are not always recognized as separate and which probably required closer analysis.

Joffe (1924) found the breaking stress to be much increased if surface cracks (a) are removed, e.g. by dissolving the surface of rock salt in water, or the surface of quartz threads in hydrofluoric acid, or (b) are avoided as in the case of freshly-drawn glass fibres (before ageing). Weakening of glass under prolonged stress is probably caused by the development of cracks and the entry of air or moisture which neutralizes the cohesive force across the cracks, for this weakening did not occur with equivalent tests in vacuum. King and Tabor (1954) found it possible to prevent brittle fracture of rock salt and ice by subjecting the materials to high hydrostatic pressure. Marked plastic deformation occurs and the plastic yield stress under these conditions reaches values very much greater than the bulk shear strength of uncompressed specimens. The effect of lubricants on the abrasive strengths of various materials was studied by Engelhardt (1945–50), who found that change of lubricant could halve the abrasive strength. The influence of liquids on boundary surface energy of an abraded body and on the sizing of the abraded particles was also investigated by Engelhardt and discussed by Ramsauer (1951).

SIZE EQUILIBRIUM

If the internal weaknesses or discontinuities and external cracks are held to facilitate the crushing of larger particles, it is to be expected that as the particles become smaller the occurrence of weaknesses would become proportionately less. This could at least partly account for the higher rate of energy consumption per unit of surface area produced as the particles become more finely ground, reported by Johnson and co-workers (1949), and by Fairs (1954). This higher energy consumption, however, has a contributory cause in the tendency of the finest particles to reunite with one another or with larger ones as demonstrated by Bradshaw (1951). It has even been suggested by Gaudin (1939, Chap. 6, and

also 1955) that since there is no known limit to the size of particle produced in comminution, it is conceivable that with some materials condensation from the gaseous state may occur during the process. Indications are, however, that no mill can produce a product of unlimited fineness since the energy required for this would also appear to be unlimited (Andreasen, 1956).

A further characteristic of the ground particle is regarded as having considerable significance in the fine grinding operation. Beilby (1921) put forward the view that in all operations such as polishing, cutting and grinding, the surface of the particle or material acquires properties different from those of the bulk. This surface is often referred to as the Beilby layer. In the case of quartz the presence of a vitreous layer was demonstrated by Ray (1922–3) by virtue of its greater solubility and by a decrease in apparent density of the particles. He calculated that after 18 hours' grinding, 31 per cent of the crystalline silica had become vitrified. Meldau and Robertson (1952) have summarized much of the work on the mechanism of the formation of very fine particles, and in discussing the vitreous layer on crushed particles, conclude that but for the presence of the Beilby layer a much larger proportion of very fine particles would be obtained on grinding.

The behaviour of solid material during size reduction is regarded by Huttig (1953) as depending on its fine structure, i.e. on the crystal lattice and linkages, and on defective places and occluded foreign bodies which weaken the linkages. With continual milling a stage is reached, as already indicated, at which the mill no longer reduces but begins to weld smaller into larger grains until equilibrium is reached. Theimer (1952) and Sales and Huttig (1954), in a new approach to the subject, have attempted to develop the kinetics of crushing in formal analogy with chemical reaction: velocity constants are introduced and orders of reaction are defined by equations, so that it is possible to derive an expression for the equilibrium particle size distribution of a ground product.

EMPIRICAL BASES OF EFFICIENCY

Since the subject of comminution has evaded all attempts at discovering a satisfactory theoretical basis to account quantitatively for more than a small fraction of the energy used in the process, alternative means have been sought for assessing the performance of machines and efficiency of operations with respect to the energy supplied. The principal aim is to be able to predict from laboratory or small-scale experiments the energy and power necessary for a required degree of size reduction with a given material and with various types of machine. Such predictions and indeed most of the developments in the field have until recently been based almost entirely on practical experience; here the prime considerations have been a desired degree or range of fineness, a desired shape of coarse product or the efficient separation of the desired mineral from gangue. The attempts at assessment from experimental data are necessarily empirical and have been mainly based on simple comparison between energy/new surface relations obtained from controlled laboratory experiments on the one hand and larger scale operations on the other. With the exception of a recent development (Bond, 1952), the linear energy/new surface relationship of Rittinger is held to be valid in most of these investigations, and has indeed received confirmation during the course of many investigations, although the experimental evidence may be open to criticism for reasons already indicated.

The early uncertainty as to the magnitude of the contribution of the subsieve fraction to the total surface of a ground product has been partly relieved by recourse to modern methods of particle size determination, and to size distribution and surface area analysis of the finer particles. The typical practice, for instance, of Del Mar (1912), when calculating the efficiency of stamp mill operations from surface area determinations, of regarding all material passing a 120-mesh sieve as lying between 120 and 150 mesh, is no longer entertained. Further improvement in accuracy is achieved by the use of shape factors, according to Heywood (1946), but there is still doubt as to the nature and extent of the surface appropriate to particular problems, and therefore as to which method of surface area determination should be relied upon.

The laboratory data for making the empirical comparisons have usually been obtained from falling-weight or small ball-mill experiments. (The recent slow-compression method of Carey and Stairmand (1952) based on associated energy data at successive stages of crushing and not on surface area is referred to later.) The energy input has been taken as the net input after deduction of mechanical heat losses from the total energy input. The accuracy is not high but is stated to be within a few per cent. The net energy input may be related to the size reduction and distribution accomplished (Coghill, 1934), or to the increase in surface area brought about. The latter may be derived from the sieve size distribution for coarse products, by physical methods based on permeability and gas adsorption for fine products or by chemical means such as the solution of quartz surface in hydrofluoric acid, or of calcite surface in hydrochloric acid. The permeability method is the one most generally used. It is convenient and rapid, is reproducible, and with the reservation already made, is very useful for comparison purposes. The accuracy of the chemical method is very much in doubt since it relies on extrapolation to zero time after removal of say 3–14 per cent of the weight of the solid during the test (Fagerholt, 1945). A much more rapid method, but applicable only to magnetic materials, for instance the mineral magnetite, relies on the establishment by Gottschalk (1935) of the linear relation between coercivity and surface area. The value of this relationship in determining grinding efficiency has been demonstrated by Dean (1939). A simple determination of the coercive force of a product, occupying only a few minutes, can be transposed directly and accurately into units of surface area. Using drop weight apparatus, a linear relation was observed between work input and surface produced, and from this relation wet ball-mill performance was found to be between 43 and 65 per cent efficient.

In the determination of efficiency of large-scale operations, the products obtained in commercial grinding equipment are compared with laboratory tests using identical methods of analysis, on the assumption that the laboratory tests have attained the maximum efficiency. In these circumstances, the efficiencies of commercial equipment have been determined by a number of investigators. They have been found to vary according to the type of mill and the fineness of product and have ranged from 3 to 60 per cent. An appreciation of the then current position was given by Prentice (1946). Wilson (1937) compared the power used in factory grinding of cement clinker with energy/surface-area data derived from a simple falling-weight apparatus and found efficiencies in the range 19–43 per cent, where the methods of determination of surface area production included the use of the turbidimeter for the finest particles. An extended investigation was carried out more recently by G. L. Fairs (1954) on three types

of rock and with several types of comminutor, using a laboratory falling-weight (impact) crusher for deriving the standard energy/surface-area data. The efficiencies found by him ranged from 4 per cent for an air attrition mill to 13 per cent for a ball mill and to 30 per cent for a swing-hammer mill delivering a coarse product. The results of the comparisons indicate that from such tests with a laboratory impact crusher the energy/surface-area rates for crushing an unknown brittle material, and the order of fineness of the product, can be predicted for commercial mills in the series investigated.

In these investigations, not only has the Rittinger hypothesis been accepted as the basis of comparison but it has received confirmation from the data obtained. Further support has been forthcoming from other recent investigations, e.g. by Gaudin (1945), by Schellinger (1952), who worked with a small ball-mill calorimeter using a variety of minerals, and by Bond (1939), who concluded that the new surface formed per unit of rotation of a ball mill is constant. Nevertheless there is no agreement as to its general validity or even as to its utility. An example of the widely held views on performance of commercial mills is provided by the opinion of Bond (1939), which was that the sole criterion of performance is an examination of the economics of the process and that efficient grinding is that which creates most surface for least expenditure of energy. Carey and Stairmand (1952) put forward the opinion that whatever the merits of the two classical hypotheses, they possess little or no advantage over empirical assumptions such as the requirement of 3–4, 5–6, 20–30 and 100–1000 kilowatt hours per tonne (short ton = 2000 lb) respectively for coarse, intermediate, fine and superfine grinding. The authors went on to describe a fundamental method of measuring the energy associated with a reduction process and gave efficiency figures for commercial grinding equipment on the basis of the associated energy concept.

The inadequacy of the two theories, already pointed out by Van Reytt (1888), had been considered by Ure (1924), Honig (1936) and others, who found that the energy relations lay somewhere between the Kick and Rittinger values. This view has been implemented by Bond (1952), who in agreeing with earlier workers that most of the applied energy is energy of strain or resilience, has proposed a compromise by regarding the energy requirement as being proportional to the square root of the reduction ratio or in inverse proportion to the square root of the particle diameter. The equation connecting the energy requirement with the reduction ratio includes a 'work index', which for a particular material is the standard on which further calculations are based, and is the energy required for the particular material to be reduced from a theoretically infinite size to 80 per cent passing a theoretical 100-micron aperture (or 67 per cent passing a 200-mesh sieve). The work index can be determined by applying the equation to experimental data. It will then enable the energy requirements to be calculated for a prescribed reduction, after which reference to manufacturers tables will indicate the size of machine and horsepower required. Work indices have been calculated and tabulated for some 60 types of material, based on the data provided by some 1200 large-scale and laboratory tests performed over a period of some years. Bond also gives an expression for calculating work indices from rod and ball-mill grindability indices, which embodies the square root factor. Bond's '3rd theory' has met with varying recognition, but has been welcomed in many quarters, as an important contribution to the problem of finding a way out of a difficult situation and of predicting power requirements for specific operations.

Holmes (1956), in his detailed study of Kick's original papers, has put forward an expression for work done, on the lines of Bond's equation, where according to the value of an exponent, the equation corresponds to one or other of the theories already discussed. The author indicates, however, that the first two theories are inadequate and that Bond's theory, although useful for prediction, is oversimplified.

A relationship of quite a different order has recently been put forward by Kiesskalt (1955) on the basis of laboratory ball-mill experiments, in which the grinding energy and lifting energy were separately estimated. The results show that for brittle materials the energy consumption is proportional to the square of the specific surface of the product.

Earlier criteria for predicting the power requirements from the resistance to grinding have been the grindability indices most closely associated with the grinding of coal for pulverized fuel. Two tentative standards have been put forward since 1930 by the American Society for Testing Materials, the tentative ball-mill method (now abandoned) and the Hardgrove machine method (now adopted). In the former the number of revolutions to attain a desired fineness is ascertained, and in the latter the surface area produced for a prescribed number of revolutions is determined. The grindability indices are calculated by reference to a standard coal. The grindability of a number of materials, e.g. cement raw materials, rock crystal, fluorspar and coke were tested by Zeisel (1953) in a Hardgrove mill and it was found that the maximum ease of grinding was recorded for a particular surface-area/weight ratio for each material and for a given set of mill conditions. The most important governing factor was the initial particle size.

THERMAL EFFICIENCY

Another method of approach with a view to avoiding the difficulties inherent in the application of surface energy data was put forward by Fahrenwald (1931) and has been taken up by later workers. Here the proportion of the net energy input considered as actually used in the breakage of the particles is simply the difference between this net input and the sensible heat developed in the operation. A laboratory ball mill suitably equipped is best adapted for the purpose. The proportions found by Fahrenwald for quartz, or in other words the thermal efficiencies based on net energy input, ranged from 7 to 20 per cent. Schellinger (1951–2) also carried out investigations with an improved ball-mill calorimeter, with a view not only to the determination of thermal efficiencies but to using the method for determination of surface energies of several minerals. The net energy absorption by the product not dissipated as heat was regarded as being transformed wholly to surface energy. The thermal efficiencies found were similar to those of Fahrenwald and ranged from 10 to 19 per cent, depending on such factors as mineral quality and pulp density, peak efficiencies in dry and wet grinding being similar. When the net energy adsorption was equated to the new surface produced, as determined by the gas absorption isotherm method, the resulting curves showed the relation to be linear. The surface energies calculated for the four minerals investigated, rock salt, calcite, pyrites and quartz, ranged from 26 000 to 107 000 ergs/sq. cm, the values being in order of hardness of the minerals. If the recognized value of, say, 920 or thereabouts, ergs/sq. cm for quartz is compared with the above value of 107 000, the latter would appear to be about 100 times too large. Thus it may be concluded that either the recognized

surface energy value for quartz is entirely wrong or else the net energy input is almost entirely unaccounted for except by assuming, for instance, that it goes into permanent straining or plastic deformation of the particles (Bennett (1941) and Kuznetsov (1954)). Some undoubtedly goes into the shearing of the suspending medium according to Andrews (1938). It is known that some of the energy input is transformed to radiant energy (Kramer, 1953), but the proportion is probably not large.

Carey and Stairmand (1952) describe in detail the 'free crushing' concept of particle comminution in which the energy required to crush a number of separated particles by slow compression between prepared faces is regarded as the minimum likely to be required for any industrial crushing process. They describe an apparatus for determining the associated energy of various crushed materials and establish curves relating to coal and quartz. These curves are then used to assess the efficiency of four proprietary grinding installations, whereby net grinding efficiencies are obtained ranging from 6 per cent for a 6-ft diameter ×23-ft long tube mill to 35·6 per cent for a high-speed beater mill. If allowance is made for the additional fan power required for closed-circuit grinding it is shown that the closed-circuit mill has a lower efficiency than the open-circuit mill. This suggests that the potential advantages of closed-circuit grinding, which are achieved in wet grinding, are not realized in some of the dry-grinding installations at present available. A possible reason for this apparent anomaly is the observation, made by Carey and Stairmand in their paper, that the efficiency of grinding falls rapidly when the fines produced are not quickly removed from the grinding zone. There is evidence to show that scavenging is far easier in a wet mill than in a dry mill and that the power requirements for scavenging and classification in a dry mill are far in excess of the equivalent requirements in a wet mill.

In general the efficiencies of commercial comminution processes are very low whatever the method of assessment. The reason is not known and Gaudin (1939, p. 135) has observed that either the current grinding principles are all wrong or the data on specific surface energy are wide of the mark; or else there is a definite physical reason why efficiencies cannot be appreciably larger, much as there is a definite thermodynamic reason why steam-engine efficiencies are limited to the range below 30 per cent. The proportion of net energy input unaccounted for in the investigations referred to lends support to this view. Djingheusian (1953) carried out an investigation at some length to test the assumption already applied in practice for many years that if the operation is conducted at a higher temperature an improvement in efficiency should result. The results apparently confirmed the assumption, for with brittle materials the grinding time and energy input were considerably reduced by raising the temperature of the wet pulp by 60°F. Djingheusian has therefore advanced a 'new concept that the absolute mechanical efficiency of grinding is a function of the internal heat energy of the material' and that 'part of the heat applied externally or generated in grinding is transformed into useful work, this being in agreement with the second law of thermodynamics'. All the relevant work was done on wet grinding, but apparently no account was taken of the fact that between the two important temperatures of comparison, 80°F and 140°F, water falls in viscosity from 0·85 to 0·47; thus the advantage attributed to thermodynamic effect might possibly be attributed more appropriately to the simple viscosity effect.

Common examples can be quoted where ease and efficiency of grinding rubbery and sticky materials are greatly improved by removing rather than by supplying heat; but for brittle materials ordinarily submitted to grinding processes, the work of Schulz (1952) on quartz, taconite and magnetite has failed to show the existence of any appreciable temperature effect for dry grinding over a much greater range, 25°–400°C, than that used in the foregoing work. Changes of properties do of course occur at higher temperatures but any such changes affecting grinding properties would not be expected to happen until the second-order transition stage is reached; this, with rocks and minerals, lies in a region very much higher than the temperatures under consideration. Acceleration of grinding, as well as other advantages, can often be obtained by the employment of well-known grinding aids, cooling and other devices.

SIZE DISTRIBUTION

The practice of crushing and grinding has always involved the operation of sieving in order to determine the abundance of various sizes in the product. In crushers with fixed openings where a coarse product is desired, simple screening is usually sufficient and a knowledge of the abundance of sizes in the desired coarse size range is easily obtained. With fine grinding a substantial proportion of the product will fall below the sieving range, the practical limit of which is a sieve of about 200 meshes to the inch. As already mentioned by Gates (1913) and Gaudin (1926), a knowledge of the size distribution in the subsieve range is of the greatest importance, particularly in view of the extent of surface area at the very fine sizes. The size analysis of such particles involves complicated and comparatively lengthy methods, the accuracy of which it is difficult to ascertain. The size distribution of crushed and ground material has been studied for many years, and more recently its importance has extended to powders for powder metallurgy. Regularities observed in the distribution of crushed or broken products of certain materials, particularly coal, have led to the formulation of mathematical expressions with which the distributions observed in sieving analysis agree more or less closely. The applicability of an exponential function was apparently first discovered by Gates (1915). Blyth, Martin and Tongue (1923) put forward an expression relating size with the number of particles. Gaudin (1926) presented sieving data in a series of curves and later proposed an exponential function to which the data reasonably conformed. Several other formulae are given by Taggart (1945) but the most widely used function has been that developed by Rosin and Rammler (1930–34), during their comprehensive investigations into the breakage of coal. This exponential function, needing only two sieving operations to establish a normal distribution curve, was found to be generally applicable to the fine grinding of amorphous and crystalline materials below the size of 1 millimetre. Its applicability was facilitated by the work of Andreasen (1930), who produced the most accurate and reliable information up to that time on the products obtained by crushing various materials in laboratory ball mills. The use of such a function, if applicable in the subsieve range, to the calculation of the specific surface of ground coal, would have a valuable connexion with pulverized fuel combustion. The significance of the Rosin–Rammler function has been described by Brown (1941), and modifications have been made, notably by Bennett and Sperling, for the purpose of widening its limited scope; but Fagerholt (1945)

undertook a critical analysis of the various formulae proposed to represent size distributions, and found it necessary to carry out a statistical investigation of the errors involved in sieve and sedimentation analyses, sampling and counting, errors on which little information appeared in the literature. When tested by the results of these investigations, he found that none of the seven distribution formulae proposed since the time of Martin, nor more general formulae embracing them, possessed the validity claimed or universal validity for a ball-mill product. Nevertheless, the presentation of the Rosin–Rammler function as modified by Bennett and Sperling has been incorporated in the German Specification D.I.N. 4190, 'Test Sieve Procedure and the Application of the Grain Size Graph'. Further, the size characteristics of dusts were investigated by Feifl (1952) and attempts made to describe them by an exponential function. A 'Characteristic Quotient' for a dust, proposed by him, is a ratio of the values at two arbitrary positions on the graph. The application of the Rosin–Rammler function to coal is referred to in a later section (p. xx).

Svensson (1953) has examined the two distribution formulae most widely recognized, those of Gaudin and of Rosin and Rammler, in the light of their relevant data and has presented a general function of which the above two formulae are special cases. This general function has been tested successfully on many size distributions of materials from different sources. Products of fixed opening crushers, e.g. jaw crushers, may not comply, or may possess two or more distributions. The greatest practical utility of the function so far has been in the calibration of test sieves, for which methods have been described and calibration tables provided. The calibration of sieves, for reasonably accurate work, by methods other than optical measurement appears to have been realized as a necessity. It is doubtful whether the products of sieving are strictly of the size indicated by the sieve number, and there is evidence that considerable error can occur by assuming that sieve fractions are strictly in accordance with the denoted sieve sizes and ratios.

In recent years endeavours have been made, by Puffe (1948), Kiesskalt (1951) and Langeman (1955), to extend the use of Rosin–Rammler graph for the determination of surface areas, these values being also presented graphically in relation to the size distribution straight lines, and having regard to particle shape factors (Heywood, 1937). A special paper is made by a German firm which enables surface area to be read from an adaptation of the size distribution curve (Rammler, Glockner, 1952). The work has also been extended in attempts to determine surface areas of distributions which deviate from the Rosin–Rammler–Sperling straight line. It is contended, however, by Bull (1955) that since the data for deriving a distribution curve are obtained only from the sieving range, it is not possible to calculate the specific surface of a very fine particulate material from such a curve. More recently, and as a practical measure, Kihlstedt, O.E.E.C. Mission No. 127 (1953), has proposed a 'classification quotient' as a criterion for a ground product. This is a dimensionless quantity K, and equals $K_{90} \times S$, where K_{90} is the sieve size in cms at 90 per cent passage, and S is the specific surface area in cm^2/cm^3. This quotient is considered to be appropriate for a purpose such as mineral dressing, where a specified fineness is to be obtained and where overgrinding (as in all grinding operations) is to be avoided. Thus the more efficient the grinding or classification, the lower is K, which should be as low as possible for the purpose in view. If surface area is assumed to be proportional to the power used, the surface produced per kilowatt-hour,

together with the classification quotient, should enable the ore dresser to determine the size of the grinding equipment required.

Distribution functions of the exponential type do not adequately describe the coarsest material. This has been attributed firstly to an insufficiency of coarse sizes to give statistically satisfactory data, and secondly to the failure of the breakage forces to penetrate the lumps completely. The inadequacy of distribution functions alone to define breakage processes in general is concluded from the work of Epstein (1948), who considered that two functions were necessary; the first he called the breakage function, which describes the size distribution, and the second, the selection function, representing the probability of breakage of particles of each size. Bass (1954) developed an equation for a time-dependent particle-size distribution, containing a characteristic function of both mill and milling charge. Broadbent and Calcott (1955) believe that the concepts of a breakage function and a selection function can be used to develop full analyses of mill products without recourse to comminution theory, particularly as the selection function introduces method and machine characteristics. They consider that breakage processes may be described in terms of various selection functions and a single breakage function, and have developed a matrix notation which greatly simplifies numerical work. The products of tests (with coal) carried out in a newly designed grinding mill, two-ball mills and a beater mill, and with shatter tests on lump coal, have been successfully analysed by this means. H. E. Rose (1956) in his investigations into ball-mill dynamics already referred to, also adopts a breakage probability concept as a basis for his work. See also E. J. Roberts (1950–51). who gives reasons for discarding surface area and particular sieving results as criteria of grinding efficiency.

The literature covering through-put characteristics, frequency of grain-size distribution, rate of grinding and rate of change of size distribution has been reviewed by Huttig and Moser (1954).

NEED FOR PHYSICAL DATA

The large amount of investigation into comminution over the last thirty years has failed to make any close approach to an adequate supporting theory and therefore to arrive at any proper accounting of the work expended in the process. The failure may be attributed to several causes. Firstly the merits of the Kick and Rillinger hypotheses have exerted a great influence on the study of comminution, far too great in the view of some investigators. It is also claimed that conclusions have been drawn on the basis of inadequate or imperfect data, derived for instance from uncertain measurements and unwarrantable assumptions, and extrapolation in the subsieve range of sizes; reduction ratios may have been too small and range too restricted, while doubtful values may have been taken for the net energy input, these being difference figures associated with known and unknown energy losses. The sieving operation itself lacks reliability, in that the material while being sieved can become abraded, that corrections must be applied for characteristic particle shapes for surface calculations, and the operation itself can only be defined empirically, chiefly in reference to timing and manipulation. Calibration of sieves by the use of powders of known size has been advocated; a method of calibration using a size-distribution function, devised by Svensson (1953), has already been referred to.

Errors from the above sources may give rise to large errors in surface-area

values and size-distribution calculations, but would hardly account for the low order of theoretical efficiency commonly accepted. Whether energy input is transformed to surface energy or strain energy, or whether a thermodynamic principle is involved, the problem of energy balance constitutes the largest gap in the knowledge of comminution. It is not likely to be solved until more is known of those aspects of solid state physics which concern dislocation and fracture development. The lack of precise data on the surface tension or total surface energy of a solid is a real hindrance to the study of processes such as catalysis, adsorption and cohesion, and to the solution of the complex problems of crushing and grinding. Data for ductile metals obtained experimentally are difficult to reconcile with those calculated for crystalline solids (Schellinger, 1952). Little is known of the surface energies and strengths of the common minerals, nor of their other physical properties, although Bond (1946) has tabulated the compressive strengths of 56 Canadian ores, the impact strengths of 72 rocks etc., and a comparison of the crushing and impact strengths of 22 materials from limestone to taconite. Wurker (1953) has put forward a plea for increasing the knowledge of the strength and elasticity of rocks, for the application of the standard methods of mechanical testing, for more exact testing and agreement on procedures, and for correlation of results with behaviour of the rocks in abrasion and comminution. To this end, a comprehensive programme of investigation has already been put in hand at Illinois University. The importance of a knowledge of the physical properties of coal has been realized by Brown (1953) and considerable fundamental investigation has been put in hand. The thermodynamic approach to comminution might offer a fruitful field for investigation, but much improvement in accuracy of measurement is called for. The magnitude and universal employment of the technical processes of comminution would justify a considerable effort in attempting to solve the problems which have arisen, even if improvement in equipment and operation will not always wait for the results.

Problems of Breakage and Structure of Coal*

R. L. Brown, M.A., F.Inst.F., F.Inst.P.
(British Coal Utilization Research Association)

Coal is a brittle material whose properties vary with direction and from one part of the coal to another. It also shows elastic and plastic properties which can be demonstrated in the laboratory. In principle these characteristics together determine the breakage and size of distribution of coal, both during mining and further preparation for use. The importance of size distribution for its various uses is as great in the case of coal as it is for any other mineral.

GRADING AND SIZE DISTRIBUTION

At any stage in the mechanical handling or crushing of coal, the product consists not of a single desired size but of a range of sizes which, in general, necessitates a separation into fractions appropriate for specific purposes. A study of the methods of grading at the pit head was carried out during 1945–7 by a committee of coal producers and distributors. It was found that the grading normally employed at collieries to produce the sizes sold under well-known designations was in accord with a basic law governing the distribution in these grades.

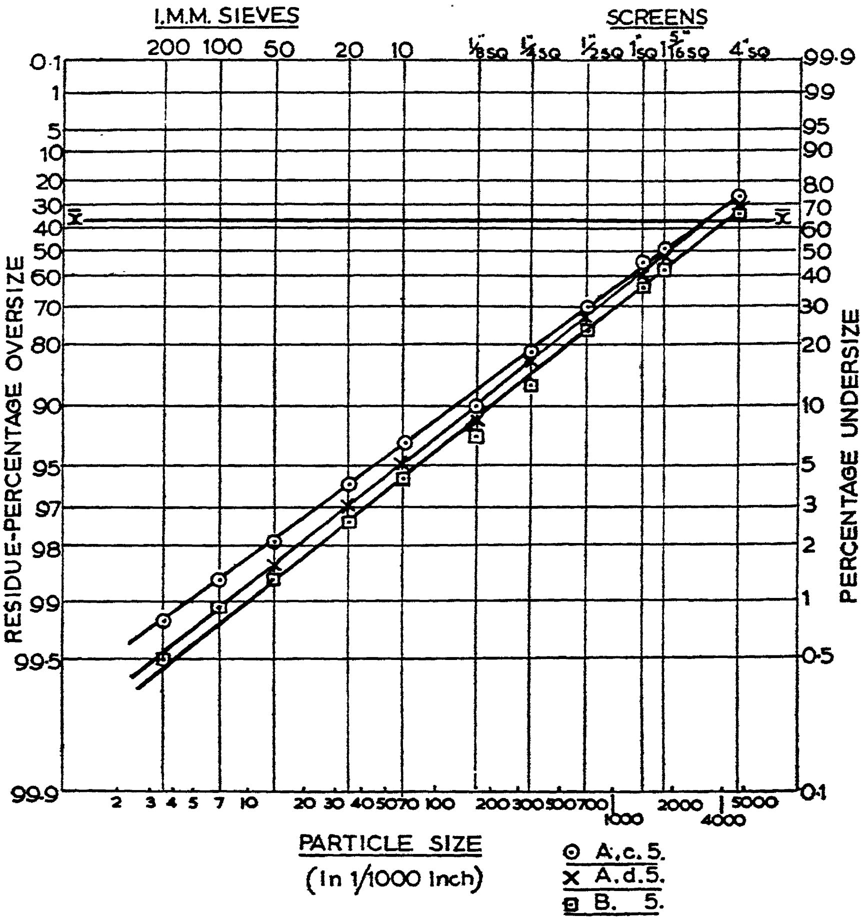
Many years previously a study by Rosin–Rammler of the distribution of the finer sizes had shown that these distributions could be represented by the well-known exponetial law: percentage oversize $= 100e^{-(x/\bar{x})^n}$. Fig. 1, based on later work, shows how closely the Rosin–Rammler law can be extended to the size distribution of run-of-mine coal over a very wide range of sizes—from a few thousandths of an inch to about 5 inches. The data for three collieries working the same seam are plotted. The co-ordinates are so chosen that the curves should be straight lines, if the Rosin–Rammler size distribution is, in fact, being produced. In addition, if the material is identical and similarly treated, the three straight lines should be coincident. The straight-line form is self-evident, and the three lines are as close to coincidence as might be expected. It can be seen also from the figure how appreciable is the proportion of 'fines' that are produced along with the inch and similar sizes of coal. For example, if 'through 10 mesh' (0·066 in. square aperture) is taken as the limit, then it can be seen that at these collieries about 4–7 per cent of the total output was of this fineness or less; at some collieries it would be 9 per cent.

Generally speaking, the distribution n may be regarded as characteristic of the method of breaking. There is support for the view that in practice a consignment of coal attains a stable size distribution in the sense that n becomes constant, although $\bar{x}$ (the constant of fineness) may decrease slowly in size. This stability of size distribution means that 'smalls', i.e. coals having only an

* Acknowledgement is made to *The Times* for permission to use abstracts and illustrations from the article entitled "The Physics of Coal", which appeared in *The Times Science Review*, *Winter*, 1953.

upper limit of size, will on the whole contain a constant proportion of fine material, and this is found to be the case.

In more complicated cases the size distribution is bimodal—as if two distributions, overlapping in size range, had been added together—but the fine mode follows a similar law.



By courtesy of the Institute of Fuel

FIG. 1. *Distribution of size of coal from the same seam worked at three adjacent collieries*

The basic law for broken coal is essentially 'non-dimensional'; it can be fitted to actual dimensions—and fitted well—but makes no prediction about them. There is nothing surprising about this, for the law is not inherently about coal, but about materials with rather generally defined statistical properties.

COAL STRUCTURE

No two pieces of coal, even from the same seam, are identical, and few pieces of coal are homogeneous within themselves. Variations in properties according

to direction are associated with the laying down of the coal measures in 'bedding planes' which were originally horizontal, but which subsequently became stressed and distorted. Against this background coal may be regarded, as a first approximation, as a precracked solid containing numerous flaws at which breakage occurs preferentially. A distinction can be made between gross and micro-structure, although it is not yet possible to relate the flaws precisely to either of these categories. Gross structure includes visible cracks and 'weaknesses' which are normally invisible but which can be detected by radiographs of coal impregnated with lead salts, and which are probably shrinkage cracks. Within the gross structure, coal exhibits also a micro or capillary structure with diameters ranging from 5 Å to 50 Å.

In general, the application of external forces causes breakage only at flaws. Disintegration at capillaries is at present regarded as occurring only under exceptional conditions, for example by dissolution in solvents.

COAL BREAKAGE

A descriptive model of a pre-cracked solid may be developed in two ways:

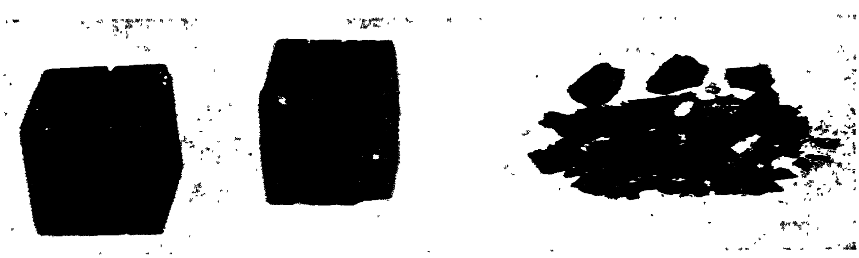
(i) It may be assumed that fracture takes place at the weakest flaws. This is the condition to be expected when loads are applied slowly. It is found in the breakage of fibres or fibre bundles where the notion of a chain breaking at its weakest link appears to be applicable. By assuming a simple statistical distribution of the strength of the flaws and using an equivalent of the statistical theory of extreme values, the strength of a specimen can then be related to its volume. Slow compression of large blocks of coal has given results approximately in accord with this theory. The theory also leads to a law of size distribution as a variant of the 'normal' (Gaussian) law in which numerous small and independent influences cause deviations from a mean value. It is difficult to distinguish experimentally between this law of size distribution and the Rosin–Rammler law, but the balance of evidence is in favour of the latter.

(ii) It may be assumed that the strength is determined by the total extent (area) of the flaws, it being supposed that breakage occurs simultaneously (or nearly so) at many points of the solid. This is necessary to account for fragmentation under impact into numerous pieces. The assumption in this case is that the load is rapidly applied and, again, a relationship between strength and size of specimen can be derived. There is some evidence that the shattering of coal follows this relationship. If, in addition, it is supposed that fracture is equally probable at all flaws, this second model leads directly to a law of size distribution from which the Rosin–Rammler law may be obtained by repeated fracture.

The difference between the two laws is essentially one of scale. The Rosin–Rammler law is a variant of the compound interest law. This latter is characteristic of a process of a steady building up, but it is not difficult to see the converse, that random shattering gives a product distributed in size according to the same law; for example, if a large piece is present, some fines must be absent, while medium-sized pieces can be present at the expense of either or both the large pieces and fines. This is true for any destructive process in which the product is on the same scale as the starting material. If, however, the product is on a smaller scale, it is subject to a conservation law, in the sense that the product is related to the ultimate units and these are associated with the long period of time during which the coal measures were laid down.

When large quantities of coal are handled, and fracture is taken to be dependent on the area of the flaws in the coal, then theory shows that a piece which is hit without being broken is likely to be weaker than a piece of the same size which had been formed from the breakage of a larger piece. This idea is clearly connected with the stability of size distribution encountered in practice and suggests, further, that efforts to reduce size degradation under random breakage, which do not at the same time reduce the energy imparted to the solids, may give a greater yield of the larger sizes, but only at the expense of their strength. What direct experimental evidence there is provides support for this argument. It then follows that the breakage of coal under the conditions normally considered cannot be controlled effectively and that whatever measures are adopted, the subsequent handling of coal may cause it eventually to revert to its stable size distribution.

Then the issue that arises is whether conscious intervention is essential for coal breakage to be controlled. In a recent experiment it has been shown that in principle this is not essential. A small cube of coal, substantially free from visible cracks, was subjected to a large number of small blows—too small, individually, to be of practical significance. At first there was no visible change in the cube, and then it began to crack both parallel with and at right angles to the applied forces. These cracks divided the cube into a few (usually fewer than eight) pieces with an almost entire absence of dust. If the shape of the cube were maintained by holding the pieces together with an elastic band and the succession of very small blows were continued, a marked change was observed; the cube suddenly shattered completely with the production of a large number of pieces and a lot of dust (Fig. 2).



(*a*) (*b*) (*c*)

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FIG. 2. *To illustrate small and multiple breakage:* (*a*), *a single fracture from many light impacts;* (*b*), *a constrained cube giving multiple successive fractures under many light impacts;* (*c*), *multiple fragmentation of the unconstrained specimen* (*a*) *under further light impacts*

ENERGY CONSIDERATIONS

The difficulties in determining energy consumption during breakage are inherent with coal as with other minerals, but involuntary breakage does not easily lend itself to systematic investigation and, since the main interest has lain in the relative proportions of fines to sized grades, a descriptive approach, mainly through the study of size distribution, was sufficient. Voluntary breakage in crushers and pulverizing plant is mainly judged, too, in terms of the size of the

products it produces. The study of energy dissipation in breakage plant is complicated by the fact that so much is lost in friction between the machine and the burden and in moving the coal through the machine that it is difficult to estimate how much is employed in the breaking of the coal.

A complete analysis of the mechanism of coal breakage would require the measurement of (i) the energy expended in fragmentation of the coal; (ii) the energy stored in the fragmented material; (iii) the kinetic energy imparted to the fragmented products; and (iv) the energy dissipated in elastic and other vibrations in the fragmented pieces.

Only the first and last of these items can at present be usefully discussed. In regard to the first, the energy expended in fragmentation is often expressed in terms of the energy required to produce the surface. Since coal contains many pre-existing flaws and prestresses, this formulation must be limited to the new surface produced and must take account of that part of the energy which goes to the formation of new flaws in the product. That new flaws can be produced is shown by the fact that the amount of breakage which a consignment of coal undergoes depends on its pre-treatment. This may be seen in shatter tests in which coal is dropped from a fixed height on to a plate. Mild treatment (say 18 in. dropping height) repeated very often makes the coal stronger; severe treatment (say 6 ft or 9 ft drops) gives about the same amount of breakage each time, but an intermediate shock can cause irregular variations in the amount of breakage.

Shatter and allied tests provide, however, only a rough-and-ready guide for practical problems and a much improved experiment is necessary if the energy expended in fragmentation is to be evaluated properly. Such an experiment is by no means easy to devise. Nor are experiments on the fourth point, i.e. relating to elasticity and plasticity, easy to carry out. Here, however, there has been recently an important development in experimental technique in which the combined use of a hack-saw, band-saw and slitting wheel enables cubes, blocks, tensile specimens, cylinders and strips of coal (down to thicknesses of 5/1000 in.) to be cut readily so that experimental techniques no longer need to be adapted to deal with irregularly shaped materials.

Many of the phenomena of coal breaking described in this article resemble those observed with other materials. It is now well appreciated that, with suitable choice of rate and magnitude of loading, most materials will exhibit both recoverable and unrecoverable deformations; for example, glass exhibits creep if given long enough and cast iron either elastic deformation or brittle behaviour according to the way in which it is treated. It is becoming clear that a similar wide variation can be found with coal. What is notable with coal is, perhaps, its ready fragmentation under moderate loads of a few tons a square inch. Whether these phenomena arise solely from the presence of flaws in the coal or whether its micro-structure is also important is not yet clear, but it will be seen below that the role of capillaries cannot, at present, be discounted.

SIMPLE CRUSHING

The important difference between slowly applied and rapidly applied forces has already been mentioned: for the former it is possible to distinguish three phenomena observed with the lower rank coals, but not with anthracites.

As the applied forces are slowly increased there is appreciable deformation

of the specimen, often, but not always, elastic, and amounting in some cases to as much as 2–3 per cent. Thus if a pair of rolls is set with an aperture l and a specimen of thickness $1{\cdot}01l$ is passed through the rolls, it can remain uncracked. If the size of the specimen be increased to about $1{\cdot}02l$, it fails in a single fracture (Fig. 3). A further increase in the size of the specimen passed through the rolls gives, first, several distinct parallel fractures and, finally, multiple and irregular fragmentation with the production of a wide range of sizes. Without knowledge of the strength of the specimen before and after passage through the rolls, this work is necessarily incomplete, but it shows that some energy must go into the deformation of the specimen before it is broken.

When a strip is passed through rolls, so that the bedding plane and the plane of the gap of the rolls are in the same direction, the strip develops a number of approximately parallel fractures as may be shown by radiographs. Again it is not known how far the weaknesses shown by the radiographs are a development of existing macro-capillaries, and how far they are imposed by the externally applied forces. What is fairly certain is that the material itself is at least an equal partner with the applied forces in determining what takes place.

The third observation relates to the size distribution of the fragmented material when complete fracture occurs. This type of breakage is substantially independent of coal rank, and is adequately represented by the simple exponential form of the Rosin–Rammler law ($n=1$). Thus, when breakage eventually takes place, it conforms to the picture of multiple fragmentation at randomly disposed flaws at which the probability of breakage is equal.

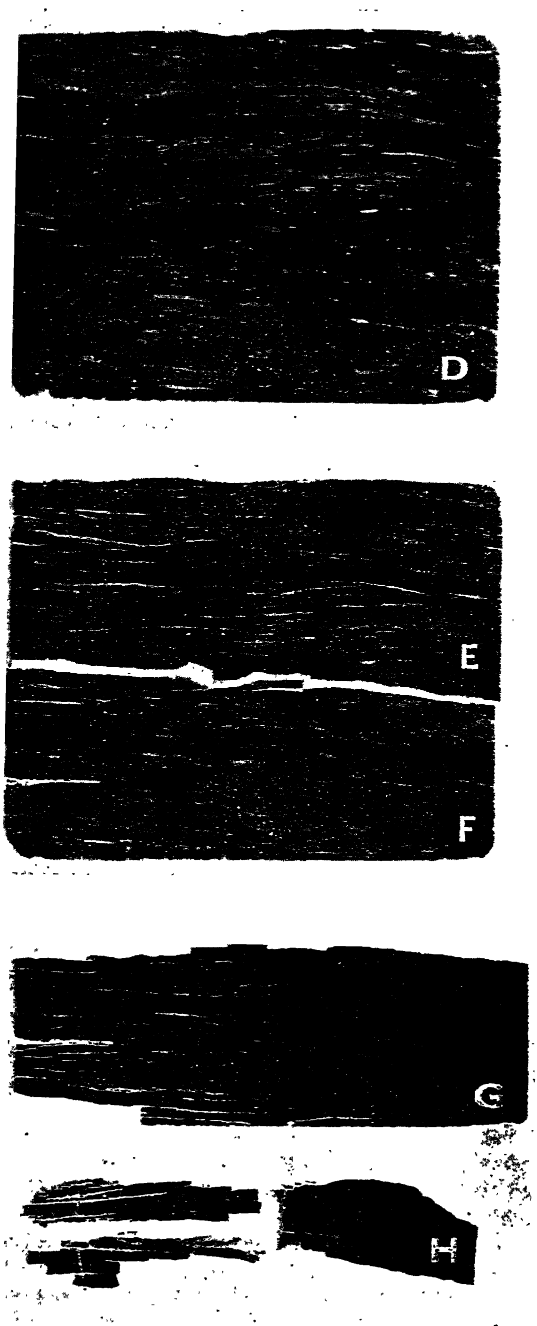
On the other hand, there is some evidence that abrasion and scratch hardness tests depend upon the rank of the coal, owing no doubt to the relevance of the micro-structure.

Another phenomenon is observed as the particle size of the coal decreases below about 100 microns (0·01 cm). For example, a 30-micron particle placed on a microscope cover-slide can be spread with a spatula, operated so that a shear stress is obtained, into a thin layer. The force required to effect this plastic deformation is again rank dependent, and also varies with the temperature at which the experiment is carried out. It would seem that, for these fine particles, surface forces are comparable with bulk forces, a suggestion which recalls the known increase of stickiness of very fine particles.

COMPLEX CRUSHING

The effect of the rank of the coal may be illustrated by a well-known system of crushing in a laboratory machine known as the Hardgrove machine. Here the coal is placed in a ball race and subjected to an arbitrary number of revolutions. Measurement of the breakage either by the specific surface of the ground product or by the percentage of fine material (through 200 mesh or smaller than 0·003 in.) produced, shows that it depends upon the rank of the coal. In the Hardgrove test, however, the sequence of events is complicated, and it is not easy to unravel the importance of such factors as the primary breakage of the original lumps, secondary and subsequent breakage and shielding of some lumps from the breaking forces.

Since in full-scale pulverizers the coal is dried, usually by circulation of hot gases, it is necessary to consider also the effect of heat treatment on grinding. The effect is again dependent on rank. Coal previously heated to (say) 130°C



(*a*), *the original strip;*

(*b*), *after first crushing, the pieces* E *and* F *being separated after removal;*

(*c*), *after second crushing, the upper piece* G *being from piece of* F *of* (*b*) *and the lower piece* H *being part of* E. *The black lines are mineral matter, and the grey are coal. The developments of weaknesses into cracks can be seen.*

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FIG. 3. *Photographs showing the fracture of a millimetre thick slab,* D, *on passing through a roller crusher with aperture* 0·98 *millimetre*

to drive off moisture and adsorbed films, cooled and then ground, breaks more easily than untreated coal. If, however, the pre-treatment temperature is higher, then the coal structure may be so modified as to make breakage less easy.

DYNAMIC TESTING

Now that techniques are available for cutting thin strips, dynamic tests involving forced transverse or longitudinal vibrations are possible. In spite of the general fragility of the specimens, a large amplitude can be obtained in a strip vibrated in resonance (Fig. 4). This points the way to the determination of elastic constants and, more important, of internal friction as functions of frequency and of amplitude of vibration. Now the internal friction is strongly structure-sensitive and the results obtained may help to distinguish the influence of flaws from that of the micro-structure of the coal. Bearing in mind that the structure of the coal can be modified by the control of environmental conditions, in particular humidity and temperature, a wide range of experiments becomes possible. Because of this last point these experiments are interesting in their own right quite apart from their technical significance.

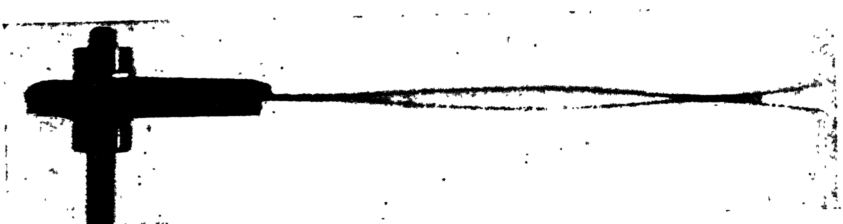

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FIG. 4. *A strip of coal* (3 *in.* × ½ *in.* × 0·01 *in.*) *is seen in resonant vibration*

MILL MECHANICS

Practical application of the researches outlined above is for the future. The findings themselves must not only be completed but put in a form in which they will be capable of technical application. Success in this will demand, as has been hinted, a more complete understanding of the mechanics of the breaking, an analysis of the functioning of the machine as carrier of material and as crusher, and a description of its crushing action in terms which can be related to the relevant characteristics of the coal structure. The grindability indices of British coals have been very recently surveyed. Tests on a ring-ball pulverizer have shown a relation between mill performance and grindability index and have brought out the importance of operating conditions on optimum performance.

Another recent advance is the proposal to apply matrix algebra to processes of crushing and grinding. Matrix algebra has been shown to provide a valuable tool, especially important in furthering understanding of mill mechanics and in enabling data to be reduced to a compact, manageable form. Thus a process of breakage can be described by two parameters: π, the proportion of particles selected for breakage, and k, the intensity of breakage. The method has been

applied to shatter tests, grindability tests, involuntary breakage in a coal-handling system and milling in both open and closed circuit systems.

The programme may appear formidable both on account of its complexity and difficulty, but the magnitude of the technical processes on which it bears justifies a considerable effort. In this country alone each year 200 million tons of coal are mined, increasingly by mechanical methods, and everything that is done to it before its final consumption involves breakage, voluntary or involuntary. Ten million tons each year are crushed at pithead. The tonnage of coal pulverized per annum is expected to rise in a few years to 30 million. Nor must it be forgotten that coal is only one of the many raw materials which pass through these processes.

Methods of Particle-Size Analysis

H. Heywood, D.Sc. (Eng.), Ph.D., M.I.Mech.E., M.I.Chem.E., M.Inst.F.
(Principal, Woolwich Polytechnic. Formerly Imperial College of Science and Technology)

Particle-size analyses determine the relative proportions of powdered materials corresponding to stated ranges of particle size, and may be assessed on a number or on a weight basis. Knowledge of the characteristics of particulate materials is of vital importance for many researches and industrial processes, both for the design of equipment and control of the quality of the product. Much research on the various methods of size analysis has been published during the last twenty-five years, and certain established procedures may now be standardized. The present object is to describe such procedures briefly, and to explain the fundamental principles upon which they are based.

The normal methods of particle-size analysis comprise sieving, microscopical measurement (including the use of the electron microscope), and elutriation or sedimentation methods based on the motion of particles in a fluid. The approximate lower limits of size to which these methods of measurement may be applied are shown in Table I. The limits of resolution by the microscope are

TABLE I

Normal Lower Limits for Various Methods of Particle-size Analysis

Method of Analysis	Lower Limit, microns
Sieving	76 normal 44 possible
Microscopical:	
Visible light	0·2 } theoretical limits of resolution
Ultra-violet in air	0·1 } theoretical limits of resolution
Ultra-violet in vacuum or N_2	0·03 } theoretical limits of resolution
Visible light, practical limit without monochromatic illumination	1
Electron microscope	0·01
Elutriation	10 light minerals 5 heavy minerals 2 with careful temperature control
Sedimentation:	
Gravitational	2 normal 1 with careful temperature control
Centrifugal	0·1

fixed by fundamental optical laws, though a high degree of skill and experience is necessary to attain these limits. The limits for the other processes are arbitrary and may, in some cases, be reduced by further improvements in technique, but

the figures given are intended as a guide to attainments possible by scientific workers without specialized experience in the subject.

SIEVING

This is the most convenient method of grading powders to a normal lower limit of 200 mesh per inch, though sieves of 400 mesh per inch are available. The accuracy of sieving analyses is in all cases limited by the inevitable weaving tolerances of the sieve cloth, which are relatively large for sieves finer than 200 mesh per inch. Standard sieve dimensions have been adopted by various countries, such as the British Standard Fine-mesh Test Sieves (B.S. 410:1943), the American Tyler Sieves and the German D.I.N. series. These standards specify the average size of aperture and give tolerances for the size and number of oversize apertures.

The process of sieving irregularly shaped particles may be divided into two stages; firstly the elimination of the fine particles which are considerably smaller than the sieve apertures, and secondly the elimination of the so-called 'near mesh' particles that will only just pass the apertures when presented in a favourable position. Fine particles should be eliminated comparatively rapidly by dry sieving methods, but if clogging occurs, then wet sieving under a stream of running water will be more effective. The difficulty in defining the 'end point' of a sieving analysis is due to the 'near mesh' particles, and this stage of sieving should always be conducted with the dry powder to avoid the effect of surface tension. The rate of elimination decreases with sieving time, but never reaches finality, and the 'end point' is usually determined when the sieving rate has been reduced to 0·1 per cent of the same weight per minute. A standard time of sieving may be adopted for routine work, provided this has been found to satisfy the above limiting rate condition. A British Standard (B.S. 1796:1952, Methods for the Use of B.S. Fine-Mesh Test Sieves) gives detailed descriptions of these sieving operations, and whilst special cases can always arise which present peculiar difficulties, the vast majority of powdered materials can be effectively sieved by the procedures described in the specification. The relationship between the size of particles classified by sieves and by other methods is dealt with in a later section.

MICROSCOPICAL MEASUREMENT

Particles are measured individually and counted by microscopical analyses, instead of being grouped statistically by a process of classification. The weight of material examined is inevitably small, though if there is a great variation in size the number of particles that must be measured to ensure a representative count may be very large. Microscopical examination is essential for a study of particle shape and other characteristics, and is especially suitable for the measurement of fine dust particles extracted from the atmosphere or from industrial gas streams which have been deposited directly on a glass slide or cover by suitable sampling appliances.

If the particles deposited on a slide are resting in the most stable position, then microscopical measurement gives the average of the two largest dimensions and takes no account of the third dimension which is parallel to the axis of the microscope. The procedure now generally adopted is to insert in the eye-piece

of the microscope a graticule on which dimensioned circles and discs are engraved. The microscope is set to give a known magnification and the particles are compared with these circles; hence the numbers of particles within defined size ranges or the frequency of occurrence on a number basis is determined. Although there is no mathematical difficulty in converting a numerical frequency to a size distribution on a weight basis, the accuracy of such a conversion depends on the extensive counting of a very large number of particles. This follows from the fact that as the weight of a particle varies as the cube of the dimensions, one relatively large particle may be equivalent to the combined weight of several thousands of the smaller particles present. A method has been developed by Fairs in which counting over a large range of sizes may be performed in, say, three stages at different magnifications. These separate counts are subsequently combined and it is thereby possible to reduce considerably the total number of particles counted, whilst preserving correct statistical control. Although the theoretical resolution with monochromatic light is about 0·2 micron, it is now generally considered that microscopical measurements below 1 micron are of doubtful value.

Considerable research has been conducted during the last few years in the development of electronic equipment for the automatic counting and sizing of particles.

The principle involved is that the particles are scanned by a spot or slit of light, the intensity of which is varied when a particle is traversed, and the effect recorded by an electronic counter. By scanning with a slit and guard spot it is possible to eliminate the edge effect, i.e. when the scanning slit only covers a portion of a particle. The sizing of particles, in addition to counting, requires more complex circuits and may be accomplished by repeated scanning using a memory device to synchronize successive traverses. In some systems it has been found more convenient to scan a photomicrograph of the particles rather than to scan the slide directly. Considerable research is in progress on all these systems and a successful particle counter and sizer will eventually contribute greatly to the speed of the microscopical method of measurement. A full description of the present stage of this research is given by ten papers in Supplement No. 3 of the *British Journal of Applied Physics*, 1954.

The electron microscope has contributed much to the study of very small particles, particularly those below a size of 1 micron. The beam of electrons is capable of greatly improved resolution, down to 0·01 micron, and enables the true shape of minute particles to be observed clearly.

The procedure of shadowing the particles with a metallic deposit enables particle shape and surface texture to be examined and gives virtually a three-dimensional impression of the particle. The electron microscope has been successfully applied to a study of carbon blacks, clay particles, silver bromide crystals in photographic emulsions and many other materials. The principles of operation for size measurement are similar to those for the optical microscope, but the even smaller size of sample and the need for very large numerical counts present the same difficulties in a more exaggerated manner.

ELUTRIATION AND SEDIMENTATION

The gravimetric size analysis of particles below sieve size is usually accomplished by processes involving the motion of particles in fluids; the equivalent

size of particle is calculated from the well-known Stokes's equation for the terminal velocity of fall, and the corresponding weight of material obtained either by direct sampling of a suspension or by some other method of determining particle concentration.

Elutriation is a process of grading particles by means of an upward moving current of fluid, normally water or air; sedimentation grades the particles according to the velocity of fall in a column of fluid at rest. Elutriation has an especial advantage if it is required to subdivide a powdered material into a number of closely-sized fractions which may subsequently be subjected to chemical or mineralogical analysis.

Elutriation by water is commonly used for the grading of minerals, the suspension being passed in sequence through tubes of increasing diameter. A novel design by Blyth departs from the earlier types of elutriator and enables six or more graded fractions to be prepared simultaneously. Air elutriation is necessary when wetting of the particles must be avoided, or when there is a large variation in particle density, as in boiler flue dust. A design of air elutriator for such purposes is incorporated in British Standard 893:1940, and the Haultain air elutriator is widely used in mineral dressing laboratories.

Sedimentation methods of analysis may be divided into two groups—cumulative and incremental. Cumulative methods measure the mean particle concentration or the suspension density over a distance ranging from the surface level to some lower datum level. Ideal incremental methods measure the concentration at the lower datum level, though in practice the range of measurement must extend over a finite depth, which should be as small as possible in proportion to the distance from the surface to the lower datum level.

Cumulative methods have some practical advantage in that the magnitude of the measurements is larger, but have the disadvantage that graphical differentiation of the experimental curve (or an equivalent process) is necessary to determine the size distribution. Two forms of this equipment in common use are the sedimentation column designed by Stairmand, and the sedimentation balance designed by Bostock.

The most frequently used of the incremental methods is the pipette, such as Andreasen's apparatus, in which a small sample is removed from the suspension at the lower datum level after various time intervals of settlement. The dispersing liquid is evaporated and the weight of suspended particles determined.

The hydrometer is a very simple instrument for measuring the density of the suspension during settlement of the particles. Although the method is generally regarded as an incremental one, the length of the hydrometer bulb is not a negligible proportion of the distance from the centre of buoyancy to the surface level. However, the method gives reasonably accurate determination of the particle-size distribution of finely powdered materials, and is frequently adopted for soil samples and clays in the pottery industry. Some of the objections to the hydrometer method may be overcome by the use of 'divers', as described by Berg. These 'divers' are sealed glass vessels loaded to have a known specific gravity and therefore float in the suspension at a level where the concentration of particles corresponds to this density. Measurement of the velocity of fall of the 'divers' permits calculation of the particle size that corresponds with a suspension density equal to that of the 'diver'.

Another method of analysis is to transmit a beam of light through the suspension at a known depth below the surface and to measure photo-electrically the

variation in the intensity of the transmitted light with time of settlement of the particles. The size distribution by weight may be calculated from such measurements if a simple theory of light extinction is assumed, but diffraction and scattering effects complicate the optical properties of suspensions of very fine particles, so that the procedure is not yet established as an absolute method of measurement. Routine checks on the quality of prepared powders may be made very conveniently without the need for sampling and weighing.

CENTRIFUGAL SEDIMENTATION

The time required for gravitational settlement of particles below 5 microns is excessive, and such particles are also subject to the effect of Brownian movement. Centrifugal separation greatly reduces the settlement time and enables particle measurements to be made down to 0·1 micron diameter. The centrifuge equipment designed by Donoghue and Bostock uses a suspension in water, and the machine marketed under the name of 'Bahco' effects centrifugal separation in an air stream. These processes are necessary to extend the range of measurements to lower size limits than is possible by gravimetric methods.

DIRECT DETERMINATION OF SPECIFIC SURFACE

Since the object of fine grinding is normally to increase the specific surface (surface area per unit weight) of the material, a direct indication of this factor is often sufficient to assess the properties of a powdered material. The two methods that are in common use are calculation of the surface area by permeability methods, i.e. the ease with which a fluid will flow through a packed bed of the particles, and the molecular adsorption method in which the surface is calculated from the volume of gas adsorbed on the particle surfaces. This latter method of measurement also includes the surface area of internal fissures which are accessible to the gas molecules but are not effective as regards fluid flow round the external surface of the particle, as in the permeability method. Consequently the two methods of measurement may give different specific surface values for the same material, according to the proportion of internal surface.

Permeability measurements are usually made with gas or air flow, but liquid flow may be used for coarse particles. The pressure drop through a bed of known dimensions and known porosity is related to the volumetric fluid flow by an equation which includes the specific surface, and this latter can therefore be calculated if all the other factors are measured. The method is used for testing Portland cement (see B.S. 12:1947) and a self-contained form of equipment has been designed by Rigden.

EQUIVALENT PARTICLE DIAMETERS

The size of an irregularly shaped particle may be defined in terms of the diameter of a circle or sphere which has some equivalent property. Thus in the microscopical method of measurement the size of the particle is expressed in terms of the diameter of a circle which has the same projected area as observed under the microscope. Equivalent spheres are those having the same volume as the particle, or the same terminal velocity in a fluid, i.e. Stokes's diameter. The dimensions of a sieve aperture through which a particle will just pass is also an equivalent diameter.

These equivalent diameters will not be the same, as they are based on different properties of the particle, and the divergence will be greater with increasing irregularity of particle shape. In such a short summary as this it is not possible to give numerical relationships between these equivalents, but the following typical figures apply to minerals having a shape similar to that of crushed quartz particles:

Ratio of projected diameter as measured by the microscope to corresponding sieve aperture	1·4
Ratio of Stokes's diameter to corresponding sieve aperture	0·9
Ratio of projected diameter to Stokes's diameter	1·6

SUMMARY

A brief account has been given of the methods available for measuring particle size. The procedure for coarse particles is to use sieves, and the weaving tolerances and methods of analysis have been specified by British Standards. Sub-sieve particles are usually measured microscopically or by sedimentation methods, and both these procedures are the subject of British Standards that are in preparation. Future research will be applied mainly to reducing the lower limits of size measurement and to mechanizing the procedures. As regards the former, the electron microscope and centrifugal methods of sedimentation are of great significance. As regards the latter, automatic particle counters are approaching a stage when machines will be available commercially. Standardization of those methods which have withstood the test of time and experience will be of great benefit to industry, but there is ample scope for ingenuity in applying new scientific discoveries to the field of particle-size analysis.

Industrial Grinding

J. C. Farrant, M.I.Chem.E., M.A.I.M.E.
(Late of International Combustion Products, Ltd)

The amount of energy required to reduce a material to a given particle size depends on a number of factors, the most important of which is the relative hardness of the material. For convenience, the hardness of a rock or mineral may be referred to the well-known Mohs scale which employs ten steps of hardness ranging from talc to diamond. The hardness criterion cannot always be applied rigidly, for instance, if the material is foliated or flaky as with graphite or some types of talc, and cannot be applied at all for such materials as rubber, natural gums and other materials which distort easily. For such materials temperature change may have a very marked effect on grindability, as it also will on the possibility of grinding hygroscopic or deliquescent materials.

Laboratory criteria for judging the performance of machines and processes have already been described, but uncertainty still exists as to the validity of their application. So many variables exist in size reduction processes, particularly the varying structure and lack of homogeneity of minerals, that the ultimate criteria of performance, it is often contended, can only be obtained by reliable field trials or full-scale tests on large representative samples. The relative power consumption when crushing to and grinding from various sizes is shown in Fig. 1*, where for the material represented the optimum size for transfer from the crushing to the grinding operation is shown to be ½ in.

For the great bulk of diversified rocks and minerals, grinding is carried out in mills which can be classified for convenience into four groups:

Group 1 Slow-speed Mills

Ball and pebble mills
Rod mills
Tube mills
Cascade-type mills

Mills of this group are universally used for grinding abrasive materials, the grinding media where used being simple in shape, comparatively cheap and easy to replace while the mill is in motion. These mills are thus capable of being run continuously for months together, a feature of prime importance in many industries. Reduction is effected by impact and attrition, and is done by the wet and dry processes in these mills.

Group 2 Medium-speed Mills

This group includes various types of roller mill in which a number of rollers bear on the vertical face of a bull ring or on to a horizontal revolving plate. The ball and ring mill could well be included in this category. Mills of this group are normally used for grinding materials whose hardness does not exceed 4 in the Mohs scale; they cover the reduction of various minerals and chemicals

* Figs. 1, 2, 6, 7, 8 and 9 reproduced by permission of the *International Combustion Products, Ltd.*

mostly in the medium and fine grinding range. Less floor space is required than with the mills of Group 1, when grinding to a definite residue on a given mesh, e.g. 1 per cent on a 300-mesh sieve. These mills are constructed for dry grinding only, generally with air classification and return of oversize.

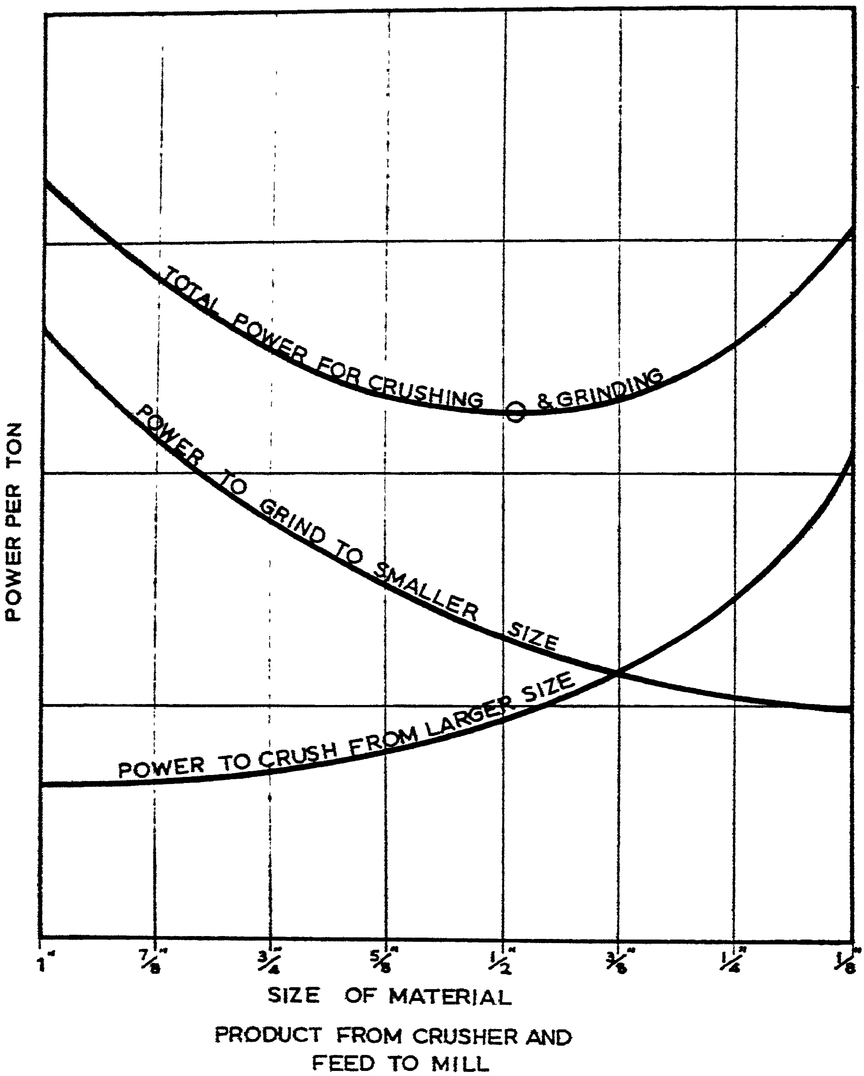

FIG. 1. *Curves showing effect on power consumption when crushing to and grinding from various sizes*

Group 3 High-speed Mills

This group consists of impact mills of the hammer, pinned disc and other types of disintegrator. These mills are relatively inexpensive and are normally used for coarse and intermediate grinding of non-abrasive materials. They are very suitable for disintegrating damp or sticky materials and for drying during

grinding, especially in view of the rapid passage of material through the mill. The amount of floor space for these mills is generally small, capital cost is low, but the wear characteristics for any but soft materials is high. Fig. 2 illustrates the maintenance characteristics of the foregoing three types of mill.

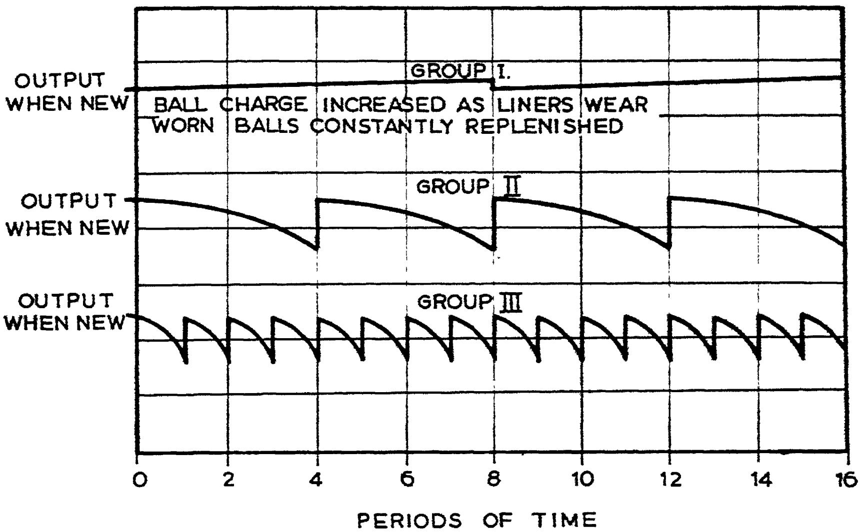

FIG. 2. *Curves showing relative life of grinding parts in different types of mills and effect on output*

Group 4 Fluid Energy Mills

This group covers the various designs of mill in which reduction is effected by bombardment of the particles against each other or against a fixed or moving plate in a stream of compressed air or superheated steam. For use with materials of hardness not exceeding 4, they are capable of giving a superfine product some of which is as small as 1 micron. The forerunner of this type of unit was introduced about thirty years ago. These mills now have many useful applications, particularly where the product value is high.

DRY GRINDING

All types of mill in Group 1, provided with appropriate feeding, discharge or air classifying mechanisms, can be used for dry grinding. The mills of Groups 2, 3 and 4 are designed for dry grinding only.

Ball and Pebble Mills

As already stated, ball and pebble mills, in series with suitable classifiers, are used for the reduction of abrasive materials in industry. A brief list covering the range is as follows:

Anthracite	Calcined Flint	Silica
Carborundum	Feldspar	Slate
Coke	Iron Borings	Zircon Sand
Chemical Products	Nickel Matte	Limestone (siliceous)
Chrome	Pyrites	

The finished products range from less than 10 mesh to 0·5 per cent residue on a 300-mesh sieve.

In dry grinding, ball and pebble mills are normally used in closed circuit except for materials such as cement clinker, where the production of the requisite range of particle sizes in the ground product justifies the open-circuit method. There are many installations of closed-circuit grinding of cement clinker, but the product is rarely used for rapid-hardening cement. With open-circuit grinding, there is certainly less oversize but there is also less of the valuable size below 5 microns. Hence the suitability of compound tube mills for this purpose.

On the other hand, a product ground to 0·5 per cent retained on a 170 mesh in open circuit, as in the cement industry, would be quite unsuitable for many other industrial purposes where specifications may require a product to be less than 0·1 per cent on a 300-mesh sieve. Here the power consumption over the time necessary to accomplish this fineness in open circuit would be unacceptable and uneconomical, even though the fan power for the air current in closed circuit is normally as high as 30–40 per cent of the power taken by the mill itself.

Additional advantages to be derived from air sweeping are the removal of fines from the incoming feed, or as in the British 'Rema' mill, the drying of the feed before entry to the mill.

The following table presents typical performance data for some minerals ground in ball and pebble mills.

TABLE II

Hardinge Ball and Pebble Mills
Dry Grinding—Air Swept

Mineral	Feed Size	Moisture Content	Product	Approx. kWh per ton	
Anthracite Anthracite	¼ in. down ¼ in.	5% 5%	90·5% −200 mesh 70% −200 mesh	43·8 20	Hot air Hot air
Carborundum	1 in.	dry	93% −100 mesh	48	Cold air
Coke	1 in.	3·2%	89% −120 mesh	20·5	Cold air
Sillimanite	20 mesh	1%	99·99% −200 mesh	125	Cold air
Zircon sand	−60 mesh 1% −200	dry	99% −300 mesh	120	Cold air
Frit Frit	¾ in. down ⅛ in. down	dry dry	All −40 mesh All −60 mesh	60 45	Pebble mill Porcelain balls

Rod Mills

Rod mills are used for the preparation of sand lime bricks, grinding from 1 in. to 10 mesh in one stage. The tendency to form a granular product in the rod mill has advantages over the ball mill in that coke, for instance, with a moisture content of approximately 10 per cent can be effectively dealt with in grinding from 1 in. to 10 mesh. The rod mill is normally run at a lower speed than a ball mill of the same diameter. It has a limited application in industry, but within its sphere it is more effective than a ball mill.

Table III illustrates the performance of rod mills when grinding coke and sodium sulphate crystals.

TABLE III

Rod Mills—Dry Grinding

Ref.	Size of Mill	Material	Size of Feed	Size of Product	Approx. Output per h	Approx. kWh per ton
H.A.	5 ft × 10 ft	Coke breeze	$\frac{3}{4}$ in.	3% + 8 mesh	5 tons	12
Sas.	3 ft × 8 ft	Sodium sulphate crystals	$\frac{1}{2}$ in. + $\frac{3}{32}$ in.	$-\frac{3}{32}$ in.	3 tons	5·5
St.J.	5 ft × 10 ft	Coke, 12% H_2O	$-1\frac{1}{2}$ in.	45% +10 30% −20 mesh	9 tons	7·5
Al.	5 ft × 12 ft	Coke	−1 in. 2·7% +4 69% −14 mesh	10% +28 mesh	0·5 tons	16·5
Am.S.	5 ft × 10 ft	Coke	37·2% + $\frac{1}{2}$ in. 45% +8 mesh 10–12% H_2O	3% + $\frac{1}{4}$ in. 67% +30 mesh	5·5 tons	9

Cascade-type Mills

This type of mill is typified by the early Hadsel Mill (Fig. 3), designed originally for wet crushing and grinding ores, but later abandoned in favour of ball and

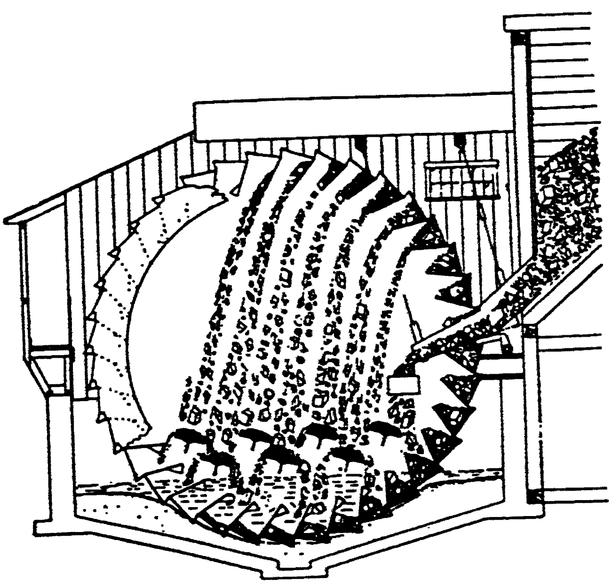

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FIG. 3. *Duplex Hadsel Mill*

tube mills. The diameter is two to three times the cylindrical length and no grinding media were present. The lumps were lifted inside the mill and were shattered by falling on to breaker plates, the fines being removed by water. This form of reduction is efficient under certain conditions, but has not shown sufficient savings for general application. Opinions differ as to the reasons for this, but certain explanations can be suggested. Minerals drawn from underground, and quarried rock, vary in size and in distribution of sizes. One particular grading may be suitable, whereas another may not. A high proportion of fines would not constitute a good feed as these would not fracture readily by their own falling weight, and fines present on the breaker plates would have a cushioning effect on the impact of larger lumps. Further, hard and tough coarse feed, in breaking down, may form a large proportion of particles of an intermediate (critical) size not large enough to shatter on impact. The cascade method of grinding, however, is currently employed in dry grinding with air sweeping, for example, in the reduction of asbestos rock, etc.

Interest in gravity impact mills, however, has revived in recent years. They are at present represented by two types of mill:

1. *The 'Cascade' Mill.* This is described with illustrations, together with a history of the cascade-type mill by Hardinge in *Eng. Min. J.*, 1955, **155** (6).

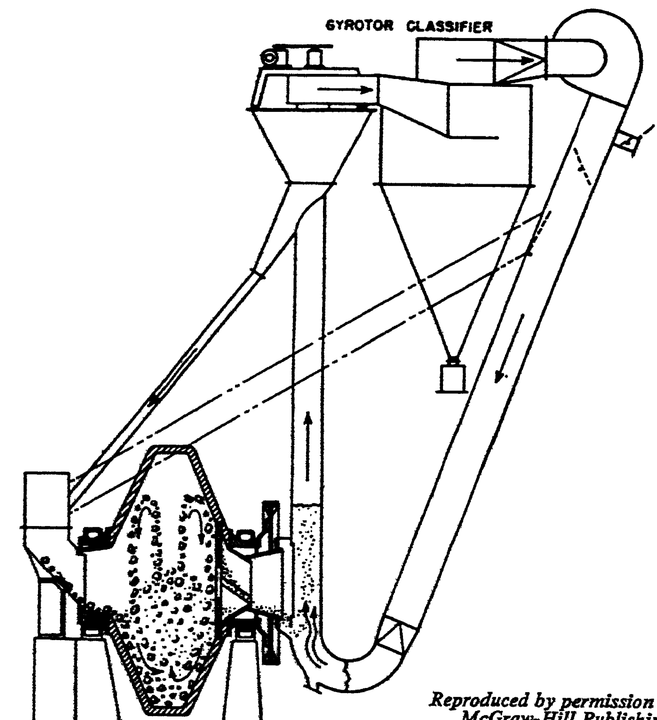

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FIG. 4. *Dry material in this model is discharged mainly by gravity into air stream which reduces the large volume of air needed for air sweeping*

Fig. 4 illustrates the mill and its method of operation.

2. *The 'Aerofall' Mill*, described by Fleck and Durocher in *Min. Congr. J.*, 1955. Fig. 5 illustrates the 17-ft model, and Tables IV and V afford a comparison

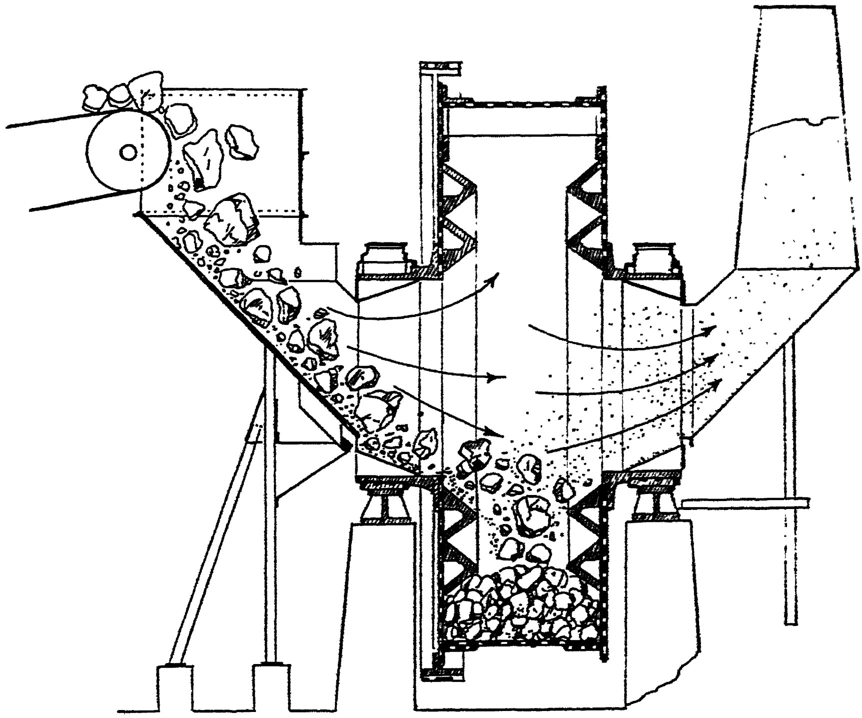

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FIG. 5. *Aerofall Mill and recovery system*

between the performances of the Aerofall mill and a rod mill in the crushing of iron ore.

TABLE IV

Screen Analysis

Mesh	Rod Mill Product Cum. % Wt. oversize	Aerofall Product Cum. % Wt. oversize
10	0·2	3·7
14	1·0	7·0
20	10·2	22·2
28	22·6	35·9
35	37·2	49·4
48	51·4	62·2
65	63·5	72·0
100	73·5	79·4
150	80·6	85·5
200	85·5	89·4

TABLE V

	Rod Mill Product % Fe	Aerofall Product % Fe
Head	24·40	24·30
Cone	60·65	60·60
Tail	8·80	7·20
Recovery	74·78	79·86
Ratio of cone	3·32	3·12

Both mills are intended for continuous dry grinding and oversize return. The addition of a few tons of balls may be necessary to ensure the reduction of the 'critical' size which escapes shattering. It will be seen that the Cascade mill has conical side sections, and that the Aerofall mill is provided with baffles on the end plates and lifters on the cylindrical. Performance data on these mills are as yet somewhat scanty and no indication is given of the cost of maintenance of the air classifying system when grinding abrasive materials.

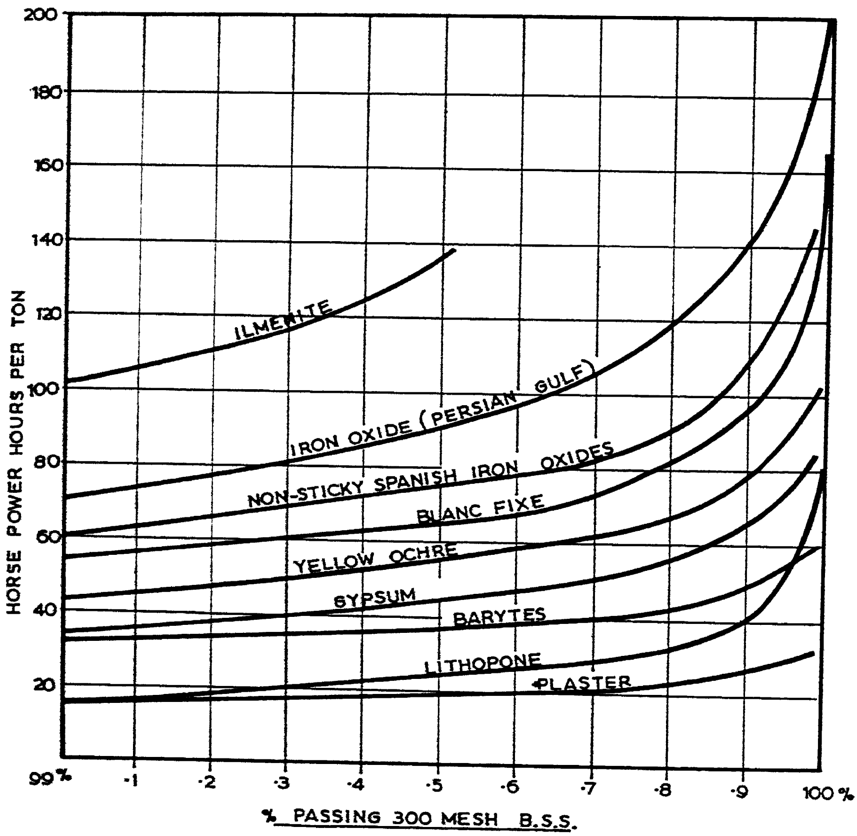

FIG. 6. *Relative power figures for fine grinding various materials*

Group 2 Roller Mills

The roller mills of Group 2 all combine air separation with the grinding of the softer minerals of hardness not higher than 4. The separator is normally of the revolving blade type with return of oversize. The mode of grinding differs considerably among the types of mill, with corresponding effects on the products.

The Raymond mill is the oldest type of multiple-roller mill in present-day use. An adaptation of the single-roller Huntington mill, it consists of a spider of 2, 3, 4 or 5 pendulums supported and driven from a vertical central shaft. The rollers mounted at the ends of the pendulums, each preceded by a plough, bear with horizontal thrust on a bull ring as the spider revolves. This mill is not the most suitable for coarse grinding, but very fine grinding is accomplished since the layer of particles on the vertical inner face of the bull ring does not build up to a thick bed. It is suitable for the grinding of materials such as ochres and paint extenders to a fineness of 99·9 per cent passing a 300-mesh sieve. A similar type of mill is the Bradley–Poitte mill, which is designed to be driven from above instead of from below.

Fig. 6 illustrates the increasing power requirements for progressively increased fineness of grind for various minerals ground in a Raymond mill. (The ilmenite was ground in a ball mill.)

Table VI gives performance data for the grinding of some varied types of mineral in the Raymond mill. Tables VII and VIII give performance data for the same mill when grinding pigments to very fine sizes.

TABLE VI

Raymond Mill (Air Swept Roller Mill)
Dry Grinding

Mineral	Feed Size	Moisture Content	Product	Approx. kWh per ton
Fuller's Earth	¾ in. down	—	99·8% −200 mesh	40
Titanium oxide	½ in.	dry	99·9% −300 mesh	100
Barytes	½ in. down	0·5%	99% −300 mesh	50
Sulphur	¾ in.	0·5%	99% −300 mesh	58
Chalk	1 in. down	0·2%	95% −150 mesh	25
Chalk	1 in. down	0·2%	95% −300 mesh	45
Talc	½ in.	0·5%	99% −300 mesh	65

TABLE VII

Data on Raymond Mill Grinding Five Different Grades of Oxides to Approximately 99·8% −240 *Mesh BSS.*

Material	Yellow Ochre	Red Ochre	Oxide B	Oxide A	Persian Gulf
Fineness (BSS.)	99·80% −240	99·80% −240	99·8% −240	99·8% −240	99·75% −240
Capacity lb/h	925	2000	570	960	670
Nett power, b.h.p.	23·8	23·8	29·0	24·2	26·7
Feed size, in.	1½ in. to dust	1½ in. to dust	1 in. to dust	1 in. to dust	1 in. to dust
Moisture (total)	1·70%	3·45%	0·75%	0·04%	1·70%
Separator vane setting	7/16 way open	½ way open	½ way open	½ way open	½ way open
Water-gauge, in.	4⅜ in.	4½ in.	4¾ in.	4¾ in.	5⅛ in.
Mill speed, rev/min	294	294	294	294	294
Exhauster, rev/min	1800	1800	2000	2000	2000

TABLE VIII

Data on Raymond Mill Grinding Five Different Grades of Oxides to 99·98% −240 Mesh BSS.

Material	Yellow Ochre	Red Ochre	Oxide B	Oxide A	Persian Gulf
Fineness (BSS.)	99·98% −240	99·98% −240	99·96% −240	99·98% −240	99·96% −240 99·89% −300
Capacity lb/h	625	1200	385	450	400
Nett power, kWh	18·5	18·20	23·5	20	20
Nett power, b.h.p.	21·0	20·70	26·7	23·8	23·8
Feed size, in.	$1\frac{1}{2}$ in. to dust	$1\frac{1}{2}$ in. to dust	1 in. to dust	1 in. to dust	1 in. to dust
Moisture (total)	1·70%	3·45%	0·75%	0·04%	1·70%
Separator vane setting	$\frac{5}{16}$ way open	$\frac{3}{8}$ way open	$\frac{5}{16}$ way open	$\frac{5}{16}$ way open	$\frac{5}{16}$ way open
Water gauge, in.	$4\frac{1}{2}$ in.	$4\frac{1}{2}$ in.	$4\frac{3}{4}$ in.	$5\frac{1}{8}$ in.	$4\frac{3}{4}$ in.
Mill speed, rev/min.	294	294	294	294	294
Exhauster, rev/min	1800	1800	2000	2000	2000

REMARKS applying to Tables VII and VIII	Very sticky	Non-sticky Easy to grind	Very hard	Moderately hard	Normal hardness

A second type of roller mill is the Lopulco mill (Loesche Mill), in which the grinding is done between heavy inclined conical rolls and a rotating table, the rolls moving freely on their spindles, and being prevented by adjustable stops from touching the table in order to prevent metal-to-metal contact and wear. The roller therefore grinds on a bed of material, but uneven distribution of the bed is automatically compensated by spring gear. The size of the product from this mill will not be as fine as that from the Raymond-type mill, but the range is wide, being from 10 mesh to 99 per cent passing a 300-mesh sieve for materials of hardness less than 4.

Table IX gives performance data for four minerals and broken gramophone records when ground in this mill.

TABLE IX

Lopulco Mill (Air Swept Roller Mill)
Dry Grinding

Mineral	Feed Size	Moisture Content	Product	Approx. kWh per ton
Limestone	1 in.	—	85% −200 mesh	17
Gramophone records	$\frac{1}{4}$ in.	dry	98% −200 mesh	62
Phosphate rock	$\frac{1}{4}$ in.	2%	75% −100 mesh	10·5
Gypsum	$\frac{7}{8}$ in.	1%	90% −100 mesh	15
Coal	$\frac{1}{2}$ in.	8%	75% −200 mesh	16

A third type of mill whose grinding action may be regarded as similar to that of the Lopulco mill is the ball and ring mill, known as the E. Mill. This mill consists essentially of two horizontal, channelled grinding rings between which is maintained a set of steel balls. The lower ring is driven through gears from the

central shaft. The feed drops onto the upper ring and finds its way between the balls, where it is ground and removed by air sweeping with return of oversize.

The E. Mill is used chiefly for grinding coal for pulverized fuel firing. The Lopulco mill is used for a similar purpose, and also for limestone, gypsum, barytes, phosphate rock etc., while the Raymond mill is suitable in addition where extreme fineness is required. The power for driving the air current through these mills is generally equal to or slightly greater than the power taken by the mill alone, owing to the resistance to be overcome in the channelling inside the mill. The fan power may be 115 h.p. as compared with 100 h.p. for the mill alone.

WET GRINDING

The mills in Group 1, with the exception of pan mills which under present conditions are largely superseded, are pre-eminent in this field. The ball-mill types are more widely used than any other form of grinding mill, since the same design of mill, with the exception of feeder, is used for wet and dry grinding.

Ore Reduction

The ball mill eliminated, with few exceptions, Stamp and Chille mills (edge runners) at the beginning of this century. As a point of historical interest the well-known Raymond roller mill is an adaptation, for dry grinding, of the original wet-grinding Huntington mill which was used for ore reduction at the end of the last century. The maintenance of the Huntington mill when grinding abrasive minerals was extremely high, but it was most satisfactory as an amalgamator when grinding gold ores.

Under modern conditions, if intermediate fine grinding is required, ball mills are rarely used without a classifier for controlling the finished product. The proportion recycled may be four or five times the output of the mill. The power used for returning the oversize to the feed end of the mill is approximately 10 per cent of the power used, this being much lower than the fan power already referred to in dry grinding.

Tube Mills

The tube mill is the oldest form of mill in which tumbling media are used to effect reduction. The length is several times the diameter and the interior is often divided into compartments for successive reduction with successively smaller ball or pebble media. The grinding to final size is usually accomplished in one pass through the mill, i.e. in open circuit. The tube mill has now largely given way to the ball mill of larger diameter because the latter is more efficient.

There are four main proprietary types of ball mill used for ore reduction and abrasive grinding generally:

1. The 'A. C.' Mill, the cylindrical mill with trunnion discharge.
2. The Hardinge Conical Mill, with natural segregation of ball sizes.
3. The Hardinge 'Tricone' Mill, with natural segregation of ball sizes. It also has the greatest volume per unit of diameter.
4. The 'Marcy' Mill, the cylindrical mill with grate discharge and lifters.

It is instructive to note that an internal classification has been accomplished with the 'Tricone' Mill (Fig. 7), by the use of a lower ball charge, about 65 per

cent normal, and a lower mill speed. A resulting pool of quiescent liquid permitted the separation of the higher specific gravity values, copper sulphide, from the siliceous gangue (Lewis (1954) and Fahrenwald (1954)).

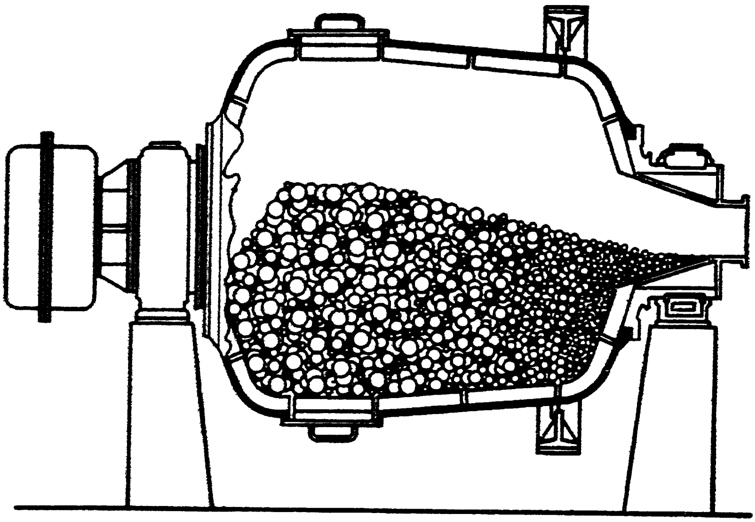

FIG. 7. *Hardinge Tricone Mill showing ball classifications, large balls in the cylindrical section, smaller balls toward the discharge end*

Some data on the grinding of some metallurgical ores are presented in graphic form. Fig. 8 shows the approximate power requirements for wet grinding in ball

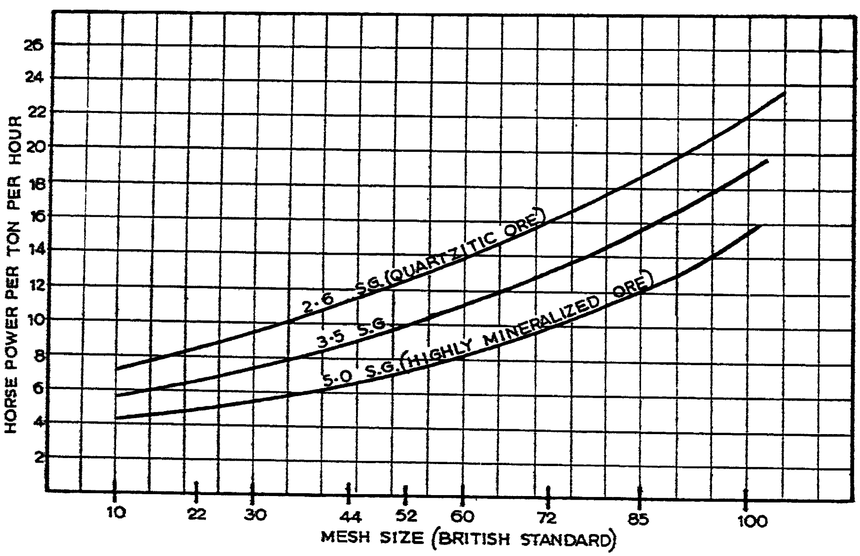

FIG. 8. *Curves showing approximate power required for wet grinding in ball mills from ½-in. feed to 90% below mesh size slated*

mills from $\frac{1}{2}$-in. feed to 90 per cent below the mesh size stated. Fig. 9 shows the particle-size distribution of various types of ore when wet ground in ball mills.

Performance data are presented in Tables X, XI and XII for the wet reduction

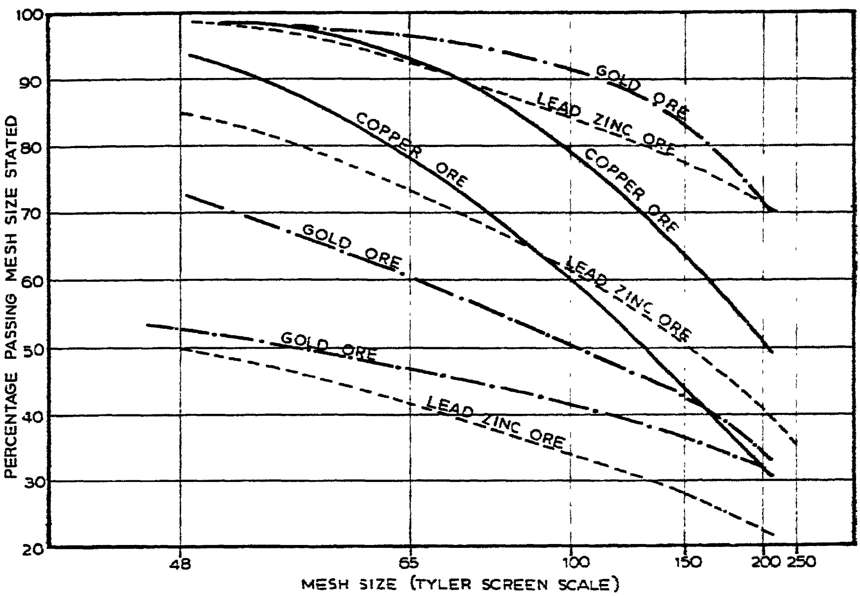

FIG. 9. *Particle-size distribution curves of various types of metallurgical ores wet ground in ball mills*

TABLE X

Gold Ore, Wet Grinding
Closed Circuit

Mine Ref.	Mill	Mill Size	Feed Size	Product	Approx. kWh per ton
883	Hardinge	8 ft × 60 in.	$\frac{1}{2}$ in.	84% −200 mesh	19
E.S.	Hardinge	5 ft × 36 in.	$\frac{1}{2}$ in.	97% −100 mesh	20
B.P.	Hardinge	8 ft × 72 in.	$\frac{3}{8}$ in.	82% −200 mesh	20
699	Hardinge	7 ft × 48 in.	7% +$\frac{1}{4}$ in.	76% −200 mesh	24 hard ore
681	Hardinge	8 ft × 36 in.	$\frac{1}{2}$ in.	85% −200 mesh	13 soft ore
701	Marcy	7 ft × 6 ft	$\frac{5}{8}$ in.	82% −200 mesh	21
629	Marcy rod mill	5 ft × 10 ft	$1\frac{1}{2}$ in.	94% −200 mesh	18
629	Marcy tube mill	5 ft × 16 ft			Quartzitic schist
—	Marcy	9 ft × 7 ft	$\frac{3}{8}$ in.	80% −200 mesh	16·5
884	Cylindrical	6 ft × 10 ft	$\frac{1}{2}$ in.	68% −200 mesh	22
674	Cylindrical	9 ft × 10 ft	$\frac{3}{8}$ in.	65% −200 mesh	17
721A	Cylindrical	5 ft × 8 ft	$\frac{1}{8}$ in. × $1\frac{1}{2}$ in.	80% −200 mesh	19·5
753	Cylindrical	8 ft × 10 ft	$\frac{7}{16}$ in. × $2\frac{1}{2}$ in.	28% −200 mesh	6 (primary grind)
670	Cylindrical	5 ft × 16 ft	$\frac{1}{2}$ in.	84% −200 mesh	21

in ball mills of gold ore, copper ore and lead–zinc ore. The effect on power consumption of grinding to finer size or in grinding from different size feeds is clearly illustrated.

TABLE XI

Copper Ore, Wet Grinding
Closed Circuit with Classifiers

Ref.	Mill	Mill Size	Feed Size	Product	Approx. kWh per ton
MA	Hardinge	10 ft × 72 in.	$\frac{1}{2}$ in.	52% −200 mesh	9·1
571	Hardinge	8 ft × 60 in. 8 ft × 72 in.	$\frac{3}{8}$ in.	40% −200 mesh	8·2
633	Hardinge	10 ft × 66 in.	$\frac{1}{2}$ in.	85% −200 mesh 69% −200 mesh	14 8
583	Hardinge	10 ft × 66 in.	$\frac{1}{2}$ in.	90% −200 mesh	11·75
531 Cy	Hardinge	8 ft × 30 in.	4 mesh	53% −200 mesh	3·50
551	Marcy	8 ft × 6 ft	−2 in.	56% −200 mesh	7·94
681	Marcy	7 ft × 5 ft	$\frac{3}{16}$ in.	−35 mesh	6·63
C	Marcy	8 ft × 6 ft	$\frac{3}{4}$ in.	58% −200 mesh	8·2
228	Marcy	6 ft × $4\frac{1}{2}$ ft	2 in.	50% −200 mesh	10·0
829	Cylindrical	7 ft × 6 ft	$\frac{1}{2}$ in.	82% −200 mesh	18
520	Cylindrical	8 ft × 12 ft	3 mesh	74% −200 mesh	10·3
541	Cylindrical	7 ft × 12 ft	1 in.	80% −200 mesh	11·2
532	Cylindrical rod mill Cylindrical ball mills	7 ft × 10 ft 3–7 ft × 10 ft	$1\frac{1}{4}$ in.	47% −200 mesh	5·8

TABLE XII

Lead Zinc Ore, Wet Grinding

Ref.	Mill	Mill Size	Feed Size	Product	Approx. kWh per ton
511	Hardinge	6 ft × 36 in.	$1\frac{1}{2}$ in.	65% −200 mesh	10·3
694	Hardinge	10 ft × 48 in.	$\frac{3}{8}$ in.	61% −200 mesh	8·3
698	Hardinge	10 ft × 48 in.	$\frac{3}{8}$ in.	35% −200 mesh	4·5
684	Hardinge	8 ft × 60 in.	$\frac{3}{4}$ in.	91·5% −200 mesh	12·75
744	Marcy	6 ft × 5 ft	$\frac{1}{2}$ in.	94% −150 mesh	9·25
—	Marcy	6 ft × $4\frac{1}{2}$ ft	$\frac{1}{8}$ in.	40% −150 mesh	3·4
563	Cylindrical	6 ft × 6 ft	$\frac{1}{4}$ in.	95% −200 mesh	11·6
CC/2	Cylindrical	7 ft × 6 ft	$\frac{3}{4}$ in.	55% −200 mesh	8·2
902	Cylindrical	10 ft × 8 ft	−2 in.	80% −200 mesh	15

Rod Mills

While ball mills are used for closed-circuit grinding, rod mills on the other hand are now almost exclusively used on open circuit, that is, one straight pass through the mill, during which the necessary reduction is effected, with a tendency towards a granular product. Typical reductions are from $1\frac{1}{2}$ to $\frac{3}{16}$ in.

for harder minerals and from 2 to ¼ in. for softer minerals. The action is by line contact, the rods at the feed end being naturally spaced wider apart than at the discharge end, thus ensuring a gradation of size along the mill and avoiding discharge of oversize, an important factor for preparing a fine feed for a subsequent regrinding in a ball mill. When dry grinding in a rod mill it is possible to use a feed material with a higher moisture content than is possible in a ball mill for a corresponding size reduction. The rod mill is not suited for fine grinding owing to the small amount of contact surface as compared with the ball mill.

Some twenty years ago many regrinding rod mills were installed for copper ores in the U.S.A., but after a few months' experiment, the rods were taken out and balls substituted since insufficient grinding was done in the regrinding rod mill to release the desired values. Table XIII presents performance data for rod-mill grinding of five ores.

TABLE XIII

Rod Mills, Open Circuit
Wet Grinding

Ref.	Mill Size	Mineral	Feed Size	Product	Approx. Output per Hour, tons	Approx. kWh per ton
St.J.	6 ft × 12 ft.	Lead–zinc quartzitic	−¼ in.	−14 mesh	18	5·2
P.2	4 ft × 10 ft	Zinc quartzitic	79% +½ in.	−⅜ in. 44% −20 mesh	16	2·3
P.D.	6 ft × 12 ft	Copper porphyry	−1¾ in.	−10 mesh	25	4·5
Qu.	11½ ft × 12 ft	Lead–zinc ore	21% +1 in.	5·8% +4 mesh 15% −200 mesh	200–250	3

Industrial Minerals

The extension of ball and pebble mill grinding has been widely adopted for various chemical and other industrial applications. Grinding calcined flint for pottery slip is an example of this application, except that owing to the extreme fineness of the finished product a hydrosizer type of classifier is used in preference to mechanical classifiers, since it is important to avoid any disturbance caused by eddying of the final overflow from the classifier. The ground product ranges in size from 57 to 65 per cent less than 10 microns.

OPERATING CONDITIONS

No attempt will be made to go into details of operation but certain conditions are essential for maximum grinding results:

1. The mineral, or substance to be ground, should be *free running* under all conditions.
2. The size of feed should be controlled, e.g. by passing the crushed product over a screen of a predetermined size which constitutes the feed to the grinding unit; the oversize from the screen is returned to the crusher.

Many materials have to be ground in the state in which they are delivered and may contain a small percentage of free moisture. When grinding to a fine state of division, packing of the fine particles may take place due to the included moisture, thus reducing the output of the unit; the particles may in fact build up, under relatively high moisture content, to such an extent that grinding would cease and the unit would have to be cleaned. Pre-drying, or drying by hot gases passing through the mill, is the only solution in some cases.

Size of Feed

The harder and tougher the material to be ground, the finer it should be crushed prior to grinding, as the power expended in crushing from, say, 1 in. to $\frac{1}{2}$ in. is less than the power absorbed in grinding from 1 in. to $\frac{1}{2}$ in. See Fig. 1, page 34.

Exceptions

In roller types of mills (Group 2) when grinding materials with a hardness factor below 2, such as barytes, talc, gypsum, etc., it is preferable to feed $\frac{3}{4}$ in. size and less in order to create a buffer between the grinding track and the rolls rather than a small feed which might induce metal-to-metal contact between the moving rolls and the grinding track.

There are more exceptions with regard to high-speed mills (Group 3), particularly where the material is easily ground. With the hammer type, grinding is done by direct impact and, under such conditions, grinding from $\frac{3}{4}$ in. to [illegible]0 mesh would show a higher efficiency than grinding from $\frac{1}{8}$ in. feed to the same mesh.

Crushing and Grinding in the Ceramic Industry

A. E. DODD, Ph.D., M.Sc., F.R.I.C., F.I.Ceram. and
F. J. GOODSON, B.Sc., M.I.Chem.E., F.I.Ceram.
(British Ceramic Research Association)

Before discussing the range of equipment used for size-reduction in the ceramic industry it would perhaps be as well to define the industry's scope. To the average Englishman, 'ceramic' means 'pottery' and nothing more, but to those engaged in, or associated with, the ceramic industry, its meaning is very much wider. Broadly speaking, anything made from clay and fired is a ceramic product; thus, in addition to tableware, the term includes wall and floor tiles, sanitary-ware, electrical porcelain, chemical stoneware, bricks and roofing tiles, salt-glazed sewer-pipes and electrical conduits, and all types of refractories. The raw materials requiring to be crushed to supply the ceramic industry therefore vary in character from very hard rocks such as quartzite to soft materials such as ball clay or talc. To deal with such a range of materials it is evident that a variety of machines will be necessary.

JAW AND GYRATORY CRUSHERS

The jaw-crusher is a common unit in the refractories industry, particularly at those works producing silica or basic refractories. They are of two general types, one having a jaw hinged at the top, the other at the bottom; the former is the original (1858) Blake design, the latter is used for dealing with large lumps of hard quartzite, which it readily reduces to about 2 in.; chrome ore and dead-burned magnesite are generally softer than quartzite and may be crushed either in a jaw crusher or a cone crusher.

The gyratory crusher was introduced not long after the jaw crusher; the crushing is effected by the to-and-fro motion of a cone gyrating about a vertical axis within a heavy steel casing. The gyratory crusher gives a product of similar grading to that given by the jaw crusher. It is used in some plants making basic refractories and may also find use in the crushing of silica rock, calcined flint pebbles, Cornish stone and feldspar.

IMPACT MILLS

The single-roll crusher or breaker operates partly by impact but also, and especially with clays, partly by a 'smearing' action. It is suitable for the reduction of materials having a hardness up to that of, say, limestone, especially if the feed consists of lumps with a soft weathered exterior and a hard core; this feature makes the single-roll crusher very useful in dealing with some of the hard shales sometimes used in making building bricks or fireclay refractories.

The hammer-mill may be said to have developed from the single-roll crusher. Hammers, pivoted on pins attached to discs rotating on a central shaft,

repeatedly hit the lumps of material charged and the reduced fragments fall through a grating at the bottom. The hammers usually reduce lumps of clay or soft rock to powder in a single blow, and this type of mill has proved efficient with many hard clays: soft stones, such as limestone or limonite pebbles, are broken up with the clay. At one plant a single hammer-mill is processing 800 tons of clay per 8-hour day. It is reported that the product is more granular than that from smooth crushing rolls, but, with clays, little can be done to control the degree of size reduction; changing the shredding plate does not greatly help, and although a change in speed can be effective from this standpoint it will be at the expense of the rate of output. At present it is very difficult, with a hammer-mill, to obtain a given grain-size for a given material.

An interesting use of the hammer-mill has been reported from a clayworks making salt-glazed pipes. The clay used contains pyrites nodules which give rise to unsightly slaggy spots on the surface of the fired pipes; these spots have been eliminated by passing the tailings from the dry-pan through the hammer-mill, the pyrites nodules in consequence being reduced to a powder, thus giving rise to a uniform colour rather than to dark spots. In this instance the complete reduction to fine powder is clearly an advantage and serves to show that grinding machinery can often be selected to meet a specific need.

CRUSHING ROLLS AND PAN MILLS

Crushing rolls find wide use in the structural clay-products industry. The rolls may be smooth, or they may be helically grooved to trap and remove stones, or they may be 'kibbled' or corrugated. In the older sets of smooth rolls, the pairs of rolls were geared together and run at about 15–25 rev/min; each of a pair of 'kibbled' or corrugated rolls, however, is generally powered by its own motor. For tough or wet clays that do not break down by fracture, it is advantageous to induce a rubbing action by driving the rolls at different speeds, one roll rotating up to four times as fast as the other, although such a wide divergence is unusual.

The reduction ratio of rolls is less than that of other crushing and grinding machinery, but they seem to produce a smaller proportion of 'fines' than most other units because the material passes through the grinding zone once only.

There has been some tendency in the ceramic industry to use high-speed rolls; these are larger in diameter but smaller in width across the roll-face than the older types of roll; the larger diameter helps to give the rolls a better grip on the material charged and so increases the reduction ratio, but even so it is generally found preferable to use two or more sets of rolls to reduce the clay to the required fineness rather than to attempt to reach this state in one operation.

The pan mill, or edge-runner, is the oldest of all types of grinding machine, and is still probably the commonest grinding unit in the clay industry, and for this reason may be described more fully. Its popularity can be attributed to its simplicity and to its ability to cope with a wide variety of clays and moisture contents: pan mills can in fact be divided into two groups—dry-pans and wet-pans. In the dry-pan, the pan rotates while the position of the mullers remains stationary; the mullers themselves revolve on a solid grinding track by friction with the charged material, their weight being supplemented, in some designs, by additional hydraulic or pneumatic pressure. In any case the effective weight must be sufficient to crush the largest pieces. The remainder of the pan base,

outside the grinding track, is perforated and the ground material is thrown across the perforations towards the periphery by centrifugal force. The fines pass through the perforations and the oversize is returned to the grinding track by suitable scrapers which feed it under the mullers. Clearly, to achieve maximum output the area of the perforations must be sufficiently large to pass that fraction of the charge which has been ground fine enough: otherwise there will be an excess of fines in the product. The ground material is usually elevated to screens from which the tailings are returned for further grinding.

The operation of dry-pans is thus continuous, and to obtain maximum output the feed also should be continuous; automatic feeders are therefore essential, particularly as passage through the grid depends on an optimum depth of feed in the pan.

The size of the largest pieces that will pass under the runner depends upon the angle of nip, which differs for different materials, according to the following relationship

$$d = D \tan^2 \theta/2$$

where d = diameter of the largest piece that will pass under the runner, D = diameter of runner, θ = angle of nip.

Generally the harder the material to be crushed the smaller the angle of nip. Thus, if the diameter of the runner is 60 in., and the angle of nip is 20°, then the largest piece that will pass under the runner will be 1·86 in., but if a softer material having an angle of nip of 40° is to be ground, the largest piece that will pass under a 60-in. dia. runner will be about 8 in.

The speed of the pan is important because, up to a certain limit, the output increases with the speed of rotation. The upper limit of speed is governed by the effectiveness of screening by the grid plates. If the speed is too high the ground material is flung by centrifugal force right across the grids to the rim and is then ploughed back across the grids to the runners at too high a speed to be properly screened. Thus pans with grids inclined towards the periphery of the pan can be run at a higher speed, because the inclination of the grids tends to slow down the material as it passes over them. Rim discharge pans, because they have no grids, can be run at a still higher speed.

As the speed is increased the effective angle of nip is reduced. This can be seen in a pan which is fed with large pieces. During normal running some of the large pieces may not pass under the runners, but if the pan is stopped it will be seen that as the pan slows down some of these large pieces will pass under the runners and be crushed. Whilst, therefore, a slow-speed pan will deal with a larger feed size than a higher-speed pan, the output will be less for a normal size of feed because the material is not passed under the runners so frequently. Hence the necessity, when the feed is of large size, to pass it first through a primary crusher.

Wet-pans may be either solid or perforated, but the former is normally used only for batch process tempering, the mullers being supported at a small distance above the pan bottom.

The perforated wet-pan is widely used in brickworks for the continuous grinding of clays that come from the pit or marl-hole in the moist plastic condition. The pan bottom is usually built up of perforated and solid sectors, the latter (known as 'dead-plates'), which take the weight of the mullers as they pass over so that it is on these plates that the actual grinding occurs; however,

it is probable that such size reduction as takes place in the perforated-bottom wet-pan is more a result of plastic deformation of the moist clay than of crushing in the normal sense; clay is, of course, an inherently fine material and a major object is to break down the agglomerates and get the water uniformly distributed as thin films around the clay particles. The general trend in pan-mill design has been to use heavier rollers and to operate at somewhat higher speeds.

Mention should be made, while discussing pan mills, of the type of mill used by the pottery industry for over two centuries; this is the pan mill that is paved with siliceous blocks over which other larger chert blocks, the 'runners', each weighing several hundredweights, are rotated by paddle arms. These mills were originally driven by water wheels and several are still powered in this way. The principal use of this type of mill at the present day is for the grinding of calcined bone for use in making bone china; this method of grinding is thought to give additional plasticity to the body.

BALL MILLS

However, the basic unit for fine grinding in the ceramic industry is the ball mill. In the manufacture of pottery, this type of mill is used for the grinding of flint and Cornish stone (the flux principally used), and for the grinding of glazes and colours; although if required in small quantities, colours are sometimes ground in mullers rotating about a vertical axis.

As would be expected, there was much difference of opinion, when the ball mill was introduced to the industry, on its merits relative to the old pan mills; it was claimed by some that the latter gave a more angular product which resulted in a stronger body, but careful examination of pan-ground and cylinder-ground flint has failed to reveal any difference in the general shape of the particles.

The grinding of potters' materials in a ball mill is generally a wet process, grinding pebbles and the crushed flint, bone or Cornish stone being charged together with sufficient water to give a pint-weight of the order of 32–34 oz. Some wet-process mills are continuous and operate in conjunction with classifiers and thickeners. For dry-process continuous grinding, air-swept ball mills have been introduced into the industry. In a modern mill in the Stoke-on-Trent area, four cylinders each 7 ft in diameter grind flint and two cylinders of the same size grind Cornish stone; for the grinding of glaze, four smaller (5 ft dia.) mills are used. Each of the larger mills produces 30 cwt of ground material in 9–12 hours.

A certain amount of fine grinding is necessary in the refractories industry, particularly in the production of an adequate amount of fine bonding material in the manufacture of silica bricks. For this purpose a high output—perhaps as much as 2 tons/hour—may be required, and a two-compartment mill over 20 ft long may be necessary. Whereas in the grinding of pottery materials it is essential to use flint pebbles (or occasionally porcelain or high-ceramic balls) as grinding media, steel balls can generally be used in the grinding of refractory raw materials, the iron contamination being less important.

OTHER TYPES OF MILL

So-called colloid mills have found some use in the ceramic industry. These mills are of various types but in general consist of high-speed rotors moving

between stators set to give a clearance of about one-thousandth of an inch. They are useful for breaking up agglomerates in pre-ground material, the action of the mill being one of dispersion rather than of actual grinding; tests with clays have shown that while flocs are broken down, the ultimate particle size of the very fine fractions is not greatly altered. Colloid mills find some use in the preparation of ceramic colours.

In fluid-energy mills the pre-ground material is caught up in air or steam jets having a peripheral speed up to 700 m.p.h., the particles being dashed against each other and shattered. It is stated that a fluid-energy mill—exemplified by the 'Micronizer'—can deal with clays containing as much as 25 per cent moisture. Practically all industrial mills of this type operate with a primary collector efficiency of 85 per cent or even higher when the product has a fineness of less than 2 microns. A particular use for the fluid-energy mill has been found in the preparation of very finely powdered talc. Attrition mills have recently been introduced to the ceramic industry; these high-speed rotary mills are swept with hot dry air, and are thus able to break down, dry and classify powdered materials in a single operation. Some clays are now being treated in this manner.

CONCLUSION

This outline of crushing and grinding in the ceramic industry, though brief, will perhaps serve to show how varied are the industry's problems in the field of size reduction. The raw materials vary from the hardest rocks, received at the works in pieces weighing up to a hundredweight, to soft clays; they may be wet or dry and the ground product that is required may vary from $\frac{1}{4}$ in. to 1 micron. To handle such a variety of materials and to produce so wide a range of particle sizes, the ceramic industry makes use of most of the available types of crushing and grinding units.

Grinding in the Cement Industry

P. DAVIS, B.Sc., A.M.Inst.F.
(Associated Portland Cement Manufacturers Ltd)

The manufacture of Portland cement in this country is chiefly by the 'wet' process in which a slurry of finely divided chalk or limestone and clay or shale is fed into a rotary kiln where it is successively dried, calcined and burnt to a cement clinker. After cooling, the clinker is ground with the addition of about 5 per cent of gypsum in a compartment tube mill to produce ordinary Portland cement.

Abroad, dry or semi-dry processes are employed in which the raw materials are dried, pulverized and fed to the kiln as a powder or as nodules formed by granulation with a small percentage of water (10–12 per cent). These processes, by reducing the amount of water to be driven off, require less fuel but may sometimes involve more grinding energy in the preparation of the raw materials than does the wet process.

For the purposes of the present summary, it is convenient to divide the manufacturing process into three major operations in each of which grinding operations play a very important part, though the type of grinding differs in each and some of the problems are peculiar to the cement industry.

The operations are:

(i) Raw material preparation.
(ii) Firing the rotary kiln, with the attendant problems of pulverized fuel preparation and use.
(iii) Clinker grinding to form the finished product.

RAW MATERIAL PREPARATION

The problem with raw material preparation is to obtain a mix of suitable chemical nature and particle-size grading for satisfactory combination of the various constituents to give a good sound cement. The basic raw materials are obtained from calcareous and argillaceous deposits, and though wide variations occur in hardness, which govern the systems of crushing and grinding employed, the problems of chemical nature and particle size are the same for all.

Experience has shown that difficulties in burning are caused by coarse (i.e. retained on 52 and 100 mesh) material and these fractions have to be reduced as far as is economically possible. On the other hand, grinding excessively fine produces no advantage in combination and a distinct disadvantage in high energy consumption. The optimum particle-size grading of raw materials therefore covers a relatively narrow range of sizes, say from 100-mesh B.S. sieve to 300-mesh B.S. sieve, depending on the chemical composition. Such a grading can be obtained by closed-circuit grinding.

(a) *Wet Process*

In Britain the majority of the industry is centred around the Thames and Medway areas where supplies of soft chalk and clay are readily available. As

dug, both contain a considerable proportion of water (approximately 20 per cent) and the most economical and convenient way of reducing them to a fine state is by 'washing'. This is done in a washmill, which is a circular brick-lined pit about 30 ft dia. by 12 ft deep. In the centre is a concrete pier supporting a vertical shaft carrying two pairs of horizontal girders set at right angles. Suspended from and slung between each pair is a harrow fitted with heavy vertical steel tines. There are four such harrows linked by trailing chains to prevent them swinging outwards when the mill rotates, the drive being through a crown wheel and pinion supported on the central pier.

Proportioned quantities of lump chalk and clay are tipped into the mill with a steady application of a stream of water. The feed is broken down by the tines and when sufficiently small passes out through a grating set around approximately half the circumference of the mill. The occurrence of hard flints presents a considerable nuisance in chalk grinding but with a washmill the majority of the flints settle out without the expenditure of energy in grinding and must be periodically removed. Several such washmills are normally used in series, fitted with successively finer sieve meshes ranging from $1\frac{1}{2}$ in. × $\frac{1}{4}$ in. slots in the first or 'roughing' mill to $\frac{1}{2}$ mm mesh in the 'finishing' mill. The coarser-mesh gratings are protected from the impact of flints by screens or iron bars. The average energy consumption of a washmill system is about 4 kWh/ton of dry material.

An alternative sometimes used in place of the finishing mill is the 'Trix' mill, which is about 18 in. in diameter and consists of a high-speed rotary cone fitted with baffles and surrounded by peripheral screens. The 'Trix' mills remove oversize material to the washmills, acting more in the capacity of classifiers than mills. Other finishing plant includes hydraulic cyclones which act purely as classifiers and tube mills which may be used to grind 'nibs' or small flints rejected by the other plant.

The choice of the plant circuit depends on the nature of the raw materials and many different combinations are in use.

With harder materials such as limestone, the lump rock as quarried is first crushed and finally ground in a wet tube mill. Primary crushing is mainly done by large, 100–200 h.p., jaw and gyratory crushers which take the quarried material as large as 2–3 ft cube and deliver at about 6 in. and below. Secondary crushing follows by cone crushers or hammer mills which supply a feed of about 1 in. maximum size to the wet tube mills. On hard crystalline limestones this system works successfully but on the softer sticky stones and marls, particularly in wet weather, it has been found necessary to use hammer crushers such as the 'Miag' type. With hammer mills it is advisable to avoid stones containing more than about 5 per cent of free quartz; otherwise excessive wear is likely to occur. Shale, which is the argillaceous material usually used with limestone, is generally washmilled before blending with the limestone at or after the tube-mill stage.

Wet tube mills vary considerably in size and design according to their particular duties. The present trend in design is towards compartment mills using three chambers containing steel media ranging in size from 3 in. to $\frac{5}{8}$ in., and fitted with hard chrome-steel lining plates. The power consumption in wet mills is about 10 per cent less than with equivalent sizes of dry mill owing to increased ball slip, and ranges from 300 to 1200 h.p. The average energy used in grinding a medium limestone (Hardgrove Index 70) so that it mainly passes the 170-mesh B.S. sieve, is about 22 kWh/ton operating at a moisture content of 35 per cent by weight of the slurry.

Classification and operation of wet tube mills in closed circuit using hydraulic cyclones is a comparatively recent development. The high solids content in the slurry calls for high pressure, up to 100 p.s.i., to obtain suitable separation, with corresponding pumping problems, not least of which is wear. The cyclones vary in size depending upon the duty and range from 4 in. to 8 in. diameter, with cone angles of about 10°.

(b) *Dry Process*

The increasing cost of fuel has turned attention towards the dry process, which is particularly attractive in the case of relatively dry materials such as limestones and shales. The process is not as yet widely adopted in Britain and the following notes are based on Continental practice. The type of mill used for dry grinding raw materials varies; some air-swept tube mills are employed in closed circuit with central peripheral discharge and quite widely used are mills of the ring-roll system with built-in classifiers. Two types used in Germany are the 'Berz' and 'Loesche' mills, the latter being developed from the old 'Loesche' mill, which was the same as the 'Lopulco' and is probably more widely known as such in this country. The 'Berz' mill is a comparatively new design employing three grinding rollers positioned by a 'spider' and held between a pressure plate and the driven bowl-shaped grinding table. The rolls move round the bowl as they rotate, unlike the fixed position rollers of the 'Loesche' and other mills.

Both mills are air swept, with hot air if necessary for drying, and closed circuiting is achieved by built-in rotary or stationary vane classifiers. The energy consumption for mill and fan is less than that of a tube mill and for hard limestone (Hardgrove Index 60) is about 14–16 kWh/ton. The proportion taken by the fan for material transport and classification increases with the size of the mill and can be as much as 7 kWh/ton in the largest mills at present made.

The recovery of ground raw material from the exit stream of air-swept mills is a sizeable problem, particularly with mills delivering up to 30–40 tons/hour. In order to ensure a minimum of wastage and pollution a highly efficient combination of cyclones and electrostatic precipitators has to be employed.

COAL GRINDING

Kiln firing follows standard pulverized fuel practice and the coal mills employed have been widely used for a considerable time. Experience has shown that for satisfactory firing, bituminous and semi-bituminous coals should not have more than 25 per cent residue on the 170 B.S. sieve. The optimum size grading is not known and research is in progress on this point, notably by the International Flame Research Committee at Ijmuiden in Holland. But generally coal mills are operated in closed circuit, producing gradings depending upon the efficiencies of the separators.

Two systems of firing are used, direct and indirect. In the first, raw coal is dried, ground and blown directly into the kiln, whilst in the second, ground coal is stored before firing. With the present variability of coal quality the degree of blending achieved by storing and the immediate control of coal feed to the kiln favour the indirect system. Simplicity in operation and cost of installation and maintenance, on the other hand, favour the direct system which is used in the majority of mills at present.

Various types of mill are employed and generally it is possible to adapt them

for either system of firing. An exception is the larger type of tube mill such as the 'Tirax', which, on account of its size, is limited to the indirect system. Other mills used include the high-speed attritor type and occasionally hammer mills, the medium-speed ring roll type, and small air-swept ball mills.

The main problem with coal-mill operation is that of dealing with wet coal and an adequate supply of hot air is necessary, particularly with ball mills, which are generally the most troublesome. The 'Rema' arrangement in which raw coal meets a stream of hot air and is classified before entering the mill assists considerably in avoiding these troubles. The performance of high-speed grinding mills deteriorates as the grinding parts wear and for the same energy consumption the ground coal becomes increasingly coarse. There is also the danger of sudden breakdowns or 'crashes', which are expensive.

It has been found difficult to obtain any general performance figures for coal mills as conditions vary from works to works. However, the types of mill at present in use require of the order of 25–30 kWh/ton for grinding, transporting and classifying coal to a fineness of 25 per cent residue on the 170-mesh B.S. sieve.

CEMENT CLINKER GRINDING

Grinding of clinker to produce the finished cement is probably the type chiefly associated with this industry and the foregoing milling problems may be less widely recognized, though none the less important.

Cement clinker is an extremely hard material and in consequence grinding costs are high. It is also very abrasive, so that wear on any type of mill is bound to be considerable. Under these conditions the tube mill is the only economical proposition, since the wearing parts, balls and liners are relatively cheaply replaceable.

Until comparatively recently open-circuit grinding was used throughout the industry. The fine tail typical of this type of grinding gives cement a high early strength, a property much in demand among cement users, and for this reason closed-circuit grinding has not been widely employed. At present the question is being investigated further, particularly in Germany and America, and some closed-circuit systems are being operated successfully and are reported as giving good-quality cements. However, as yet the open-circuit tube mill predominates.

The mills vary considerably in size and power, ranging from 20 to 40 ft in length, 5 to 8 ft in diameter and 300 to 1200 h.p. Present practice is to use the larger 800 to 1200 h.p. sizes separated into 3 or 4 compartments by slotted diaphragms and often fitted with lifters to assist the flow of cement through the mill. The sizes of grinding media used vary from 3½-in. to 4-in. forged steel balls in the first chamber to ¾-in. cast-iron balls or cylindrical media in the last chamber. To prevent direct wear on the shell, liner plates are fitted and many designs are available each having claim to some improvement in grinding efficiency. Generally they are of stepped form for use with the larger media and slightly ribbed or plain in the remainder of the mill. A special conical lining plate has been successfully used abroad; this segregates the various sizes of media and prevents the smaller sizes working towards the inlet end of each chamber, as they do in normal linings, to the detriment of the grinding efficiency.

The design of tube mills has been developed to an extent that outputs and power consumptions for clinker grinding can be predicted with accuracy.

Normally the volume loading adopted is 30 per cent, giving a charge weight of as much as 80 tons in the larger mills. Higher loadings up to 40 per cent are used in closed circuit mills, particularly in America.

A rapid calculation of the power requirements of any tube mill grinding cement clinker can be obtained from the formulae:

$$\text{h.p.} = 0{\cdot}1 . D . W . N$$

where D=diameter of mill (ft), W=weight of media (tons), N=r.p.m. of mill.

The optimum speed is generally expressed in terms of the critical speed, ranging between about 70 per cent of critical for fine grinding and 80 per cent for coarser grinding. A compromise has to be made in the case of combination tube mills where coarse and fine grinding occur and usually a speed of 75 per cent of critical is employed.

The critical speed can be calculated from the formula:

$$N_{\text{critical}} = 76{\cdot}6/\sqrt{D}$$

For the production of ordinary Portland cement the energy consumption is about 30 kWh/ton.

Clinker feeding is done by rotary feed tables, belt feeders and in certain cases weigh-feeders. Gypsum is fed in simultaneously with the clinker, the two rates being coupled to ensure correct proportioning. The coupling is adjustable to allow for variation in the quality of the gypsum. The maximum size of clinker feed to the tube mill is about $\frac{3}{4}$–1 in. because with clinker larger than this the necessary size of grinding media becomes impracticable. On the other hand it has been found uneconomic to crush the feed below $\frac{3}{4}$ in. since it is reduced below this size in the first few feet of the mill.

Considerable heat is developed in the grinding of cement clinker and some mills are therefore water cooled, since coating of the grinding media, which is liable to develop at temperatures above 100°C, will reduce the efficiency of the grinding operation.

In the manufacture of white cement, iron contamination has to be avoided and flint pebble charges are used in mills lined with 'Silex' blocks. The grinding is not very efficient as the pebbles have a density similar to that of clinker, and the energy consumption is up to 60 kWh/ton. Denser ceramic media are used in America and France, but the first cost is high, being in the region of £200/ton as against approximately £8 for pebbles.

For producing very fine special cements, grinding aids have been used to prevent coating of the media. Fats and resins have proved successful and for clearing a badly coated mill a small quantity of coal or resin has often been very useful. The quantities of such aids must be kept low (below about 0·05 per cent) to avoid giving the cement air-entraining properties, unless these are desired.

CONCLUSION

The mills described are of a wide range of designs and perform a wide variety of duties requiring from 4 kWh/ton for washmilling soft chalk to 60 kWh/ton for grinding white cement using pebbles. The essential feature of grinding in cement manufacture is that the mills, like all cement works plant, must be reliable enough to work without a stop for months at a time.

From the design and performance aspect most is known in the industry about clinker grinding using tube mills and these can be designed to give desired outputs based on experience and relatively simple theory. On the other hand, less is known about the scope of other grinding plant such as ring-roll mills and attritors and there is room for investigation into their characteristics and performances.

Crushing and Grinding of Minerals

T. ANDREWS, A.C.S.M., ASSOC. M.I.M.M.
(*Huntington, Heberlein & Co., Ltd*)

The reduction of minerals by crushing and grinding may be regarded as having one or other of two main objectives: the attainment of a size appropriate for the direct industrial application of the mineral, e.g. barytes, sand, aggregate; or the release of metallic or ore inclusions from an unwanted matrix with a view to maximum separation. In both cases, quarrying, as a rule by explosives, followed by coarse crushing of the quarried lumps and then by intermediate or secondary crushing of the product, is the normal course of reduction and, with a few exceptions, is irrespective of the ultimate objective. After this, the methods of fine crushing and grinding and the accompanying ancillary processes are chosen in accordance with the objective in view and with certain physical properties of the mineral. In the later stages of reduction, power consumption increases rapidly with fineness of product, and it follows therefore that grinding beyond the desired size or optimum range is to be avoided as far as possible. In practice it is more often the case that power is unnecessarily expended due to inadequacy of the ancillary equipment, its inherent inefficiency or unsuitability.

CRUSHING

The basic principle upon which a crusher works is the application of the necessary force in a suitable way to overcome bonding forces by which a lump of mineral is held together. In machines where the opposing crushing members are held mechanically apart this force is applied either as direct pressure or squeezing until fracture occurs; or by impact, where the rock may either be freely suspended, e.g. as in hammer mills, or stationary as in stamp mills.

In such machines the feed size of mineral may range from ¼-in. cube—as in the case of smooth-faced rolls—up to large run-of-mine or quarried lump of 30-in. cube.

The determining factor in the choice of the primary crusher is often the tonnage to be handled and the size of the largest lumps, for where both are large the gyratory type has many advantages, foremost of which are lower power consumption, first cost and choke feeding—in fact the gyratory may be 'buried', and truck loading is common practice. The jaw crusher on the other hand needs a feed controller, which in the case of the very large units involves the provision of a massive apron feeder the cost of which may be as high as £10 000. The jaw crusher, however, is capable of receiving a larger lump for any rated capacity and in certain cases is applied as a primary sledging breaker, although, unless there is an abnormal quantity of massive lumps present in the mine or quarry, it would seem preferable to break such boulders by the use of explosives.

The following comparison between the respective feed and discharge areas of a 48 in. gyratory and a 48 in. × 60 in. jaw crusher serves to illustrate some of the foregoing factors:

Feed area:

Jaw crusher	one opening of 20 sq. ft
Gyratory	two openings each of 43·4 sq. ft

Discharge area:

Jaw crusher	3·1 sq. ft
Gyratory	10·9 sq. ft

An important advantage of the jaw crusher over the gyratory crusher is that of being able to deal with materials having a high clay content, although this advantage is less where discharge openings are large.

SECONDARY CRUSHING

It is assumed, for the present purpose, that intermediate crushing is not necessary and that the run-of-mine or quarried mineral has, in one pass, been reduced in size so that all is below say 6-in. ring size. From this stage forward the utilization of the product assumes primary importance. For example, if the economic mineral is wolfram or scheelite, necessitating separation from the matrix by hydro-gravity separation, the further size reduction must be effected with the aim of minimizing the production of 'fines', whereas if flotation separation is to be used no such consideration applies. Similarly, in the production of road-surfacing aggregate the shape of the secondary crushed product is important and here particles approaching cubic shape are preferable.

Prior to secondary crushing it is important and desirable to remove the fines already below the set of the crusher. Run-of-mine and quarry product when accepted into the plant comprises rock of varying sizes some of which is below the primary crusher open setting, but its removal from the crusher feed at this stage is not so important as in secondary crushing where the feed is of a shorter range and hence packing by fines more serious. Moreover the mechanical and siting problems involved in removing, say, minus 6 in. ring size from quarried rock of 30 in. cube would outweigh any increased efficiency of the crushing operation.

It is desirable to remove undersize material from the crushing unit for a number of reasons: power has been expended in effecting its size reduction; its presence in the crushing unit and the packing of the voids between the uncrushed oversize not only reduces throughput but results in increased wear and higher power costs. If, in addition, the fines are of an argillaceous character the presence of such in the crusher will prove to be an intolerable nuisance.

The secondary crushers to be considered are the following: cone-type gyratory, rolls, hammer mills, gravity stamps. This range of four secondary crushing machines includes two in which size reduction is effected by pressure and two by impact. Of the four to be discussed the hammer mill has its own particular field of use from which other types of crushers are excluded; rolls are extensively used in the crushing of minerals preparatory to gravity separation and whilst much of their former use has been taken over by the cone gyratory, the spring roll makes an efficient crusher to sizes from $\frac{3}{8}$ in. to $\frac{1}{16}$ in., taking over where the cone crusher leaves off. Despite occasional claims to the contrary it is unwise to effect size reduction much below $\frac{3}{8}$ in. by cone crusher.

The cone-type gyratory, of which the "Symons' is perhaps best known, is pre-eminent as a secondary crusher and is capable of effecting a size reduction

ratio of the order of 6–8:1. This type of machine is best employed in close-circuit with a screen but is unsuitable for minerals of an argillaceous character. Protection against the inclusion of steel in the feed is imperative and all units of this type are more satisfactory handling dry feed. In cases where the feed is damp to wet it is advisable to limit the closed setting to ½ in. and unless extra water can be added to ensure the non-build-up of fine material in the bowl regular inspection is advisable.

The use of hammer mills is in the field of softer minerals, such as gypsum, barytes and limestone, and particularly where the presence of clay would most definitely exclude the use of crushing machines in which fracture of the mineral is effected by pressure. In this latter field in particular, the hammer mill is also used as a primary crusher. The hammer mill is an impact breaker and is capable of effecting large reduction ratios. Where the mineral is soft and would easily clog, this type of crusher is extensively and successfully employed, modifications being made to the cage to facilitate screening and retention of material in the grinding zone.

The gravity stamp, which crushes by impact and is a wet crusher, is being superseded by the rod and ball mill in fields where formerly it was extensively used. In particular, the stamp was used extensively in crushing gold-bearing quartz and cassiterite lode material as in the Cornish mines. The stamp gives a very big reduction ratio—feed of from 1½ in. to 2 in. is reduced to 30 mesh—but its inefficiency from the viewpoint of power expended must be largely attributed to the 'hit and miss' method of removing the pulp from the stamp box.

The use of smooth-faced rolls as a secondary crusher preparatory to ball milling in a lead–zinc differential flotation is exemplified by practice at the Zinc Corporation Ltd mill, Broken Hill, New South Wales. Here run-of-mine ore is reduced to minus ½ in. in two stages of primary crushing and subsequently by slow-speed rolls to ¼ in., the latter being in closed circuit with screens. The use of rolls in this case was influenced by the desire to feed to the ball mills a product minus ¼ in., to be able to operate the circuit wet, and to use bucket elevators to raise the roll discharge to the close-circuiting screen. Further advantages in this particular installation were the elimination of the dust problem and the ability to change the size of the ball-mill feed to a finer product if desired.

GRINDING

It is obviously desirable to limit size reduction to the minimum consistent with economic considerations, particularly as grinding costs are considerably greater than crushing and tend to rise disproportionately with decreasing particle size of product.

In the recovery of minerals, crushing and grinding of the matrix is, apart from the actual separation, the most important phase of the process. The objective in this case is to produce free mineral particles, which may either be gangue or economic mineral; if grinding of either is taken further than necessary such work represents waste of energy. It does not follow from this, however, when treating a heterogeneous mineralized body, that it would always be economical to halt the grinding process to eliminate a proportion of the gangue minerals, but it is certainly preferable to regrind a middling product, even of substantial weight proportion, rather than to overgrind freed economic and waste mineral. For minerals recoverable by froth flotation, overgrinding is less critical—nevertheless

the grinding plant should be designed so as to avoid the production of superfines as much as possible. For the satisfactory operation of mineral recovery by froth flotation the upper limiting size is of the order of 250 microns.

GRINDING PRACTICE

(a) *Wet Grinding*

In ore-concentrating processes, tumbling mills probably account for more than 95 per cent of total throughput when grinding to 30 mesh and below. They are almost wholly employed in the wet grinding processes. They may be rod or ball mills according to the process employed in the subsequent recovery of the contained economic mineral. When gravity separation by reciprocating tables is practised, either rods or balls may be used and in either case it is good practice to operate in closed circuit with a vibrating screen. There is less chance of overgrinding when using a rod mill but an effective insurance against this, in the case of the ball mill, is to operate the circuit with a relatively large circulating load.

Modern practice in the grinding of ore containing cassiterite is exemplified at the Geevor mine (Cornwall), where Hardinge cylindro-conical ball mills operate in closed circuit with vibrating screens. This type of circuit is satisfactory where grinding to 500 microns is sufficient to effect liberation but it is doubtful whether screening beyond 30 mesh B.S.S. is sound practice, owing to the relatively short and irregular life of the mesh.

Rod mills are not suitable for fine grinding of minerals but present practice favours the use of rod mills as preliminary grinding units operating in open circuit. The rod-mill discharge at minus 16 mesh is further ground in a ball mill operated in closed circuit with a mechanical classifier of the rake or spiral type. Rod mills in such installations may be likened to multiple rolls, size reduction being effected by impact and pressure.

In order to minimize the wastage of power by unnecessary size reduction of minerals all modern fine-grinding installations have ball mills in closed circuit with classifiers. Inasmuch as nearly all the economic minerals in mine ore are heavier than the gangue minerals the former suffer overgrinding because of the concentrating effect of hydro-classification. This is particularly so in the case of the softer minerals of high specific gravity such as galena, and in order to obviate this defect a concentrating machine is often interposed between the ball mill and the classifier.

Unfortunately, there are many classifier installations of relatively low efficiency and an appreciable percentage of material below the optimum mesh-of-grind returns to the grinding unit trapped in the returning sand load. An investigation into the most satisfactory 'policeman' to be interposed between the grinding unit and the concentrator would be advantageous. The use of vibrating screens down to and including 72 mesh B.S.S. would bridge a wide existing gulf, but risk of failure of the screen cloth in addition to the large screen area required for large tonnages of fine-mesh material precludes the use of screens excepting for relatively small tonnages.

Hydrocycloning of the ball-mill feed may, in certain circumstances, be satisfactory but the extreme reliability of the mechanical classifier (rake or spiral) is such that it is likely to be favoured for the immediate future.

Mineral grinding in closed circuit with ball mills would gain in efficiency if

the desideratum of the flotation circuit were divorced from the process of size reduction.

Pulp density is an important factor in wet-grinding mills—too high a pulp density, expressed more conventionally in terms of percentage solids by weight, would restrict the grinding force, as the pulp would serve as a cushioning factor. An extremely low pulp density would also be disadvantageous because too little of the pulp would adhere to the surface of the balls and would result in the balls being in contact with relatively clean surfaces. This condition is readily noted in practice when the sound from the mill is harsh and metallic—conversely a dull sound indicates too high a pulp density.

A pulp density, at a specific solids/water ratio, is dependent upon the specific gravity of the solid phase; it follows that with minerals of high specific gravity a higher pulp density can be permitted than with minerals of low specific gravity. To the experienced millman, the consistency of the pulp is a sure guide to optimum conditions, but automatic aids such as the Harding 'electric ear' are reported to give satisfactory control after optimum conditions have been established.

(b) *Dry Grinding*

The following physical characteristics of minerals must be taken into consideration in deciding upon the most suitable size-reduction installation:

1. Hardness.
2. Abrasiveness.
3. Stickiness.
4. Free moisture content.
5. Chemical stability.
6. Purity of finished product.

Hardness and abrasiveness must be considered in relation to the wear of the grinding parts, and such minerals as iron pyrites, silica and siliceous minerals (feldspar for example) should be ground in dry tumbling mills. In grinding to 30 mesh or coarser the mills are preferably close-circuited with vibrating screens, but below this mesh air-swept mills and air cyclones should be employed. Maintenance, however, is heavy with air-swept mills, particularly in the cyclone and trunking, and in the case of such an abrasive mineral as pyrites special lining material to the trunking must be fitted. Such a lining is readily available.

Most minerals exhibit adhesive properties when damp and a number have this characteristic even when perfectly dry. Iron ochres, talc, chalk, are a few in this category. For satisfactory dry grinding of minerals the free moisture content should be as low as possible, particularly if comminution to a fine size—say, minus 300 mesh—is desired. Limiting moisture in this case should be of the order of 0·5 per cent and if the mineral possesses adhesive characteristics, satisfactory operating practice demands a moisture content of the order of 0·2 per cent. Roller mills with inherent vibrating effects are the most suitable machines for this class of mineral. The introduction of hot air or gas into the feed and milling system is widely practised in grinding damp and adhesive minerals.

Purity of final product is an important consideration in many cases such as

in the grinding of barytes for the paint trade. The presence of minute traces of iron is prohibitive in such a case, and therefore in the grinding of minerals where purity of colour is an overriding consideration, pebble mills are used. It is to be noted, however, that the wear of silica pebbles is far greater than that of steel balls and if silica in the final product is detrimental, tumbling mills manufactured in special steel may be necessary.

Grinding in the Field of Dyestuffs and Organic Chemicals

C. TOYNE, B.Sc.(Tech.)
(Imperial Chemical Industries Ltd, Dyestuffs Division)

Grinding operations in the dyestuffs and organic chemicals field cover a wide range of products and machines. The materials are expensive and quality control is of paramount importance; energy consumption is a secondary consideration. The operations can be conveniently subdivided as follows:

(a) Grinding and mixing of colours and diluents in the standardization of dyestuffs and pigments.
(b) Preparation of dyestuffs intermediates or other organic chemicals for further processing or for sales.
(c) Paste milling of vat dyestuffs in the manufacture of dispersible fine powders.

(a) In these operations the dried colours and diluents are ground separately and then mixed in batches with adjustment according to colour test until the required blend is achieved. The usual diluent is common salt but other materials such as starch, talc, sodium sulphate and sugar are sometimes used. The essential requirements are that the standardized colour should be a free-flowing powder, free from lumps, with uniform appearance and tinctorial strength. For the majority of colours the particle-size specification is 100 per cent < 14 B.S.S. (1200 mu), 99·5 per cent < 36 B.S.S. (420 mu) and 95 per cent < 60 B.S.S. (250 mu). Finer grinding would increase the dust-control problem without contributing appreciably to the rate of solution in the dye-bath.

Although the physical properties of the unground colours vary considerably the majority are fairly soft and friable; in general the hardness is comparable to gypsum or rock salt, i.e. 2 on the Moh hardness scale. The grinding duty is therefore light and can be met by many types of mill such as beater mills, ball or rod mills, pinned-disc and attrition mills. Perhaps the most important factor influencing the choice of equipment is the large number of different products which must be dealt with in relatively small amounts in the same units. A production level of 100–500 tons/annum of one colour can be rated as a high output, and for every large production colour there may be 20–30 in the range 1–100 tons/annum. Campaigns on one colour brand must be relatively short to meet sales requirements without building up unduly large stocks. The cost of labour in handling the products and particularly in cleaning the mills and ancillary equipment between batches of different colour is therefore a high proportion of the total expenses. Scrupulous care is required to avoid contamination and on this account a mill of simple design which facilitates opening or partial dismantling for cleaning and inspection is preferred.

Pin-disc and hammer-screen mills fall into this category and are available in sizes suitable for the throughputs required in colour standardization. For example, a mill equipped with 2-ft diameter pinned discs, or a hammer-screen

mill of comparable size, has a representative capacity of 1 ton/hour and power consumption 10–30 kWh/ton according to the hardness of the material. Comminution in these mills is partly by impact on the moving parts and partly by attrition in the highly turbulent concentrated suspension of particles in the air passing through the mills. The screen-beater mills are fitted with a retaining screen (usually $\frac{1}{32}$-in. holes), which ensures the absence of coarse particles but otherwise appears to have no appreciable effect on the grading of the product. Blinding of the screen may occur due to overloading, particularly with waxy materials. The pinned-disc mill has no safeguard against the passage of oversize particles, although this is more likely to occur with sticky or damp material which may build up temporarily on the pegs. In both mills the risk of choking and caking on the walls is reduced by the intake of air, which also holds the product temperature down to 20°–60°C according to condition of operation. Combined hammer and fan mills, without screens, which in recent years have been introduced for general-purpose intermediate and fine grinding in the dyestuffs field, have a relatively greater air throughput and an internal air-classification effect. Mills may also be provided with pneumatic separators for tramp iron at the feed inlet and when these are used in conjunction with the usual magnetic separator, experience has shown that the chances of foreign matter entering the mill are small. The magnetic separator alone is useful but not entirely reliable.

In practice the control of feed size and rate is vitally important and a kibbler or shredder is usually employed on the mills. This is located at the base of a hopper into which the crude unground materials are charged and the feed rate is adjusted by the speed and size of aperture of the kibbler disc. In some installations feed rate is adjusted automatically by an instrument controlling kibbler speed by consumption in the mill. The power load is adjusted to the optimum for each product.

Heat-sensitive dyestuffs and intermediates are sometimes encountered and special precautions may be required to avoid ignition or quality deterioration. In such cases where standardization with inorganic salts is practised it is safer to grind the sensitive material in admixture with a large proportion of the diluent. Caking in the mill is likely to lead to overheating and decomposition, and care in drying feed materials usually helps to avoid this trouble. Attrition mills and beater mills with induced air flow have proved quite safe for grinding these products provided feed rate is carefully controlled and the above precautions are taken.

The physical appearance of some brands of colour is so important a selling point that the mill must be selected on this criterion more than any other. Speckiness, caused by incomplete coating of white particles of diluent by the colour, and dullness of shade are faults of this kind which often can be eliminated only by a grinding unit in which comminution takes place by rubbing and shearing rather than by impact action. For this duty the ball or rod mill or the edge-runner are usually employed.

(b) Dyestuffs intermediates or other organic products such as rubber chemicals, textile auxiliaries and medicinal products are usually prepared for sales by fine grinding; anything from 95 to 100 per cent through a 100 B.S.S. sieve may be specified. Although most of these materials would fall into the same hardness class as dyestuffs the range of physical properties is wider and the throughput of a given mill may vary considerably from product to product.

Attrition mills are commonly employed with pneumatic conveyance to blenders or hoppers fitted with dust stockings. This type of mill has the advantage that the internal classification can be adjusted to facilitate the changes of throughput and specification required. Low melting point or sticky materials need special care in establishment of operating conditions, in particular air/product ratio. Caking near the feed inlet or on the rotor pegs may be prevented in such cases by increasing the air rate. On the other hand, high air rates often lead to build-up and blockages near bends caused by heat generated by friction in the pneumatic transfer ducts. A balance must therefore be struck between these effects. In the most difficult cases where sticky materials are ground the efficiency may be so rapidly impaired that stoppages for cleaning are necessary every few hours. For very fine grinding (say 100 per cent < 10 mu) fluid-energy mills and ball mills are used. The latter are cheaper in operating cost but fluid-energy mills are very useful in cases where absence of contamination is of special importance (e.g. penicillin).

(c) Wet ball or gravel milling is employed as part of the complex process required to manufacture dispersible vat dyestuffs and pigments. It is essential in these cases to achieve a primary particle size of less than 3 mu and to break down the aggregates formed by these particles. This can best be done by batch milling the paste with addition of a dispersing agent for periods which may extend to several days according to the product. The mills are usually tile- or rubber-lined and range in size from 10 to 200 gal; the larger mills may require cooling by water sprayed over the shell. Various grinding media are used, including sand, gravel, porcelain balls and steel balls. Of these, gravel (Dorset pea) appears generally to give the best result, with low contamination by breakdown of the grinding media, and low cost.

Fire and Explosion Hazards in Crushing and Grinding Operations

F. E. T. KINGMAN, Ph.D., F.R.I.C.
(*Joint Fire Research Organization*)

Any grinding or crushing operation must produce, by accident or design, large quantities of fine material, and if the original material is combustible, the dust produced may give rise to serious fire or explosion hazards. The more serious of these hazards is that of a dust explosion; thus, many solid materials such as coal, starch or cork, sulphur and many dyes which burn quietly when in comparatively large lumps may burn with explosive violence when ground to a fine powder and dispersed in the air as a dust cloud. Such dust explosions can result in catastrophic damage, and it follows therefore that in any works where fine dust is used, manufactured or produced as a waste product great care must be taken to prevent a dust explosion or to minimize its effects should it occur.

Suspensions of dusts in air are very similar in many ways to mixtures of flammable gas and air. Thus, in each case, explosion only occurs when the concentration of the combustible lies within certain limits (the limits of flammability), though the limits are much wider with dusts than with many gases. For practical purposes, the lower flammability limit for most dusts may be taken as 0·02 oz/cu. ft, but the upper limits have not in general been determined and in any case are not of such great practical importance, since if a rich dispersion occurs settling will soon produce a mixture within the explosive range. Further, as with flammable gases, no explosion can occur unless an igniting source is present.

The problem of flammability of dusts has been studied for many years by the Factory Department, Ministry of Labour and National Service, at the Safety in Mines Research Establishment, Buxton. A very large range of dusts has been examined and classified according to their relative explosion hazard. A summary of the results has been published in *Factory Form* 830 (1952). This work together with practical experience in industry shows that a very wide variety of materials can give rise to dust explosions. The Factory Form classifies dusts according to their relative ease of ignition and Class 1, i.e. those dusts that can be ignited by a small source and that will propagate flame readily, includes such materials as flour and grain dusts, cork and coal, many of the synthetic plastics and certain particularly dangerous metals such as magnesium and aluminium.

The industries and processes most liable to dust-explosion hazards fall into three classes:

1. Milling industries, such as flour mills, where the dust is the final product of the process.
2. Industries in which the dusts form one or more of the raw materials.
3. Industries where the dust is produced as a waste product by processes such as grinding and polishing.

In practice it will probably be found, at least in modern plants, that the explosion hazard is fairly well understood in works in which processes falling into either of the first two groups are concerned. It may therefore be expected that the plant will be designed to reduce the hazard, and suitable precautions taken to minimize the consequences of any explosion. In the third group, however, it may well be found that the dust is only regarded as an annoying waste product which has to be disposed of with as little effort and cost as possible, without any real appreciation of the risk of a dust explosion.

In any process involving the production of dust by grinding it will be necessary to take precautions against dust explosions throughout the whole process, since the possibility of an explosive concentration of dust is not confined to the grinding process itself. This latter operation is of course the point at which safety precautions must be first applied, since the production of a dust cloud is inherent in the nature of the operation and the possibility of ignition is increased by the amount of energy required to carry out the operation; also much of this energy is used in heating up the material rather than in the actual process of subdivision. In many cases the concentration of dust in the mill may be too high to permit of an explosion but the dust if ignited may pass out of the mill and cause an explosion in other parts of the plant. Every effort should be made to eliminate ignition sources, e.g. by the use of magnetic and other separators to remove tramp iron and other foreign hard bodies, and it is preferable to carry out the grinding operation in small segregated units. With some hazardous materials this may involve installing the grinding plant in a separate blast-proof enclosure. In some cases it may be necessary to carry out the grinding in an inert gas.

Similar safety precautions will apply to all parts of the plant, however, and as it is rarely possible to ensure complete immunity from dust explosions, it is necessary to consider the possible means of minimizing the destructive effects of the explosion.

Further advice on this can be obtained from 'Notes on the Installation of Plant for the Grinding of Flammable Materials', Ministry of Labour and National Service, *Factory Form* No. 896, 1950, as well as from other publications.

These precautions obviously are closely related to the design of the plant, and it cannot be too strongly emphasized that in any plant in which explosive dusts are handled or produced the safety measures should be considered as an essential of the initial design of the plant. Two further points must be made. When a dust explosion occurs in a plant handling or producing dust, the primary explosion in the plant may disrupt the plant. This, in itself, may not cause serious damage outside the plant. If, however, the dust which must inevitably escape from the plant during normal running has been allowed to accumulate on ledges, window sills, girders, etc., the primary explosion may disperse and ignite this loose dust. The secondary explosion thus caused is likely to cause much more serious damage than the primary explosion. It is therefore essential to prevent the accumulation of dust in a factory by systematic cleaning, preferably by a vacuum exhaust system.

Finally, the collection of the dust may cause some hazard, and dry collectors should be placed in a position outside the factory where an explosion would cause least harm. If the dust is a waste product it may be possible to collect by wet scrubbers placed as near as possible to the source of emission of the dust,

thus eliminating the explosion hazard; this latter course is a statutory requirement in the grinding and polishing of magnesium.

These notes on the hazards of dust explosions and the necessary safety precautions are only designed as an outline of the problem, which is extremely wide and varied, and in which each individual plant has its own peculiar problems. It is recommended, therefore, that where new problems arise, and particularly where a new plant is under consideration, expert advice should be sought. The Government Department most closely concerned with this problem is the Factory Department of the Ministry of Labour and National Service, and a considerable amount of information has been published by the Senior Chemical Inspector and his colleagues, whose advice is available when dust explosion hazards are being considered, either in the construction of new plant or the operation of plant already in existence.

In addition to the explosion hazard when combustible dusts are dispersed as a cloud, a serious fire hazard may arise from the presence of quiescent layers of dust.

Many common dusts such as wood and cork dust, even when spread out in layers, will smoulder readily in still air. The smouldering is readily initiated even by a small source of ignition such as a cigarette end. Smouldering proceeds slowly (e.g. a few inches per hour in still air) but will continue as long as the thickness of the dust layer is above a certain minimum value which may be as little as one-tenth of an inch.

The rate of smouldering is increased by air currents over the surface of the dust, and the minimum thickness required for sustained smouldering reduced, but it is not possible to induce open flaming with fine dusts, since the dust is blown away before the rate of burning is rapid enough to cause flaming. If, however, the smouldering dust is in contact with coarser combustible material such as shavings, paper, etc., the smouldering dust will initiate normal flaming combustion of this material.

Smouldering can also occur in deep piles of dust, even if the source of ignition is buried within the heap. In such circumstances the rate of smouldering may be very slow, and smouldering may go on undetected for days, weeks or months before it bursts through to the surface.

Like the explosion hazard, the smouldering hazard of dust layers and piles can only be eliminated by careful design of plant and buildings and above all by the maintenance of a high standard of housekeeping and constant vigilance.

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Fundamental Aspects of Crushing and Grinding

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values much below those determined from crystal-structure data, and this is attributed to surface flaws in the crystal mass. Work required for crushing should not be appreciably more than that required for new surface energy. Blocks of cryst. NaCl crushed between a falling ball and a mortar supported on deformable supports showed an energy requirement of 100–150 g-cm/sq. cm of fresh surface (determined by permeability methods). The crushing 'efficiency', always less than 1% on surface-energy assumptions, decreased as crushing proceeded to finer sizes. Recrystallization phenomena were considered to have no effect, but X-ray photographs showed that plastic deformation existed in all the crystal fragments. This plastic strain was not present in other materials (e.g. quartz) crushed by the same method and giving a uniform crushing efficiency whatever the size range. Conclusions: with halite, the surface-energy relationship was curvilinear. Plastic deformation was observed by use of X-rays. 29 refs.

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15. **Classified Grinding Research.** ANDREWS, L. *Trans. Instn Min. Metall., Lond.*, 1938–9, **48**, 141–207; *Bull. Instn Min. Metall., Lond.*, 1938, (409), 1–25; *Ceramic Abstr.*, 1940, **19**, 19. The theory is advanced that the rise in temperature in a wet grinding mill is due mainly to two causes: (1) molecular stretching and shearing of the strained suspending medium surrounding the solid particles, and (2) molecular agitation in particles not fractured by the blows received. Results are given of laboratory and works tests which appear to confirm this theory. The application to milling and classification practice is discussed and recommendations made for research on these lines.

The experiments were done in a modified Joule calorimeter and calculations made on the basis of surface tension values.

16. **Zerkleinerungstechnik und Staub (Crushing Technique and Dust).** ANSELM, W. 1950, Verein deutsche Ingenieur Verlag, Düsseldorf. A 59-page publication with numerous tabular and graphic presentations of data accompanying the eight sections, with appendices containing physical data for some hundred materials. 75 refs. are appended. (1) Estimation of size by sieving and sedimentation. (2) Size distribution and standard of fineness. Tables of numerical evaluation of factors for size distribution calculations for many types of fine and coarse mills and for many materials. (3) Results and applications. Experimental results of the size distribution for various materials and various crushers and grinders are discussed and presented in tabular form. (4) Surface estimation. The application to various materials and cement varieties is discussed. Results for various mills are tabulated with reference to the formulae derived. Mathematical analysis. (5) Energy consumption is discussed, methods of calculation are described and experimental data are tabulated. (6) Grinding resistance. Methods of assessing grindability are described and experimental results tabulated for many materials. (7) Energy consumption and efficiency for various sizes with different materials. (8) Energy balance of a compound mill. [P]

17. **Surface Area Production and Energy Requirements in the Grinding of Solids.** ANSELM, W. *Zement-Kalk-Gips.*, 1953, *6* (1), 15–22; *TonindustrZtg*, 1953, *77*, 62. An experimental study, based on Rammler computations for several materials, in which the calculated values are compared with the Blaine test values. The coarse surface effect in larger particles needs further investigation. It appears beyond doubt from the energy requirements and surface calculations, that crushing into coarse grains is more expensive in energy than the production of fine particles, *contrary to opinions hitherto prevailing*. Results are presented in graphic form. The Blaine test appeared to give a larger amount of surface than the calculated quantity. 17 refs.

18. **The Preparation of Ceramic Raw Materials. III–VI.** AVENHAUS, W. *Ziegelindustrie*, 1950, **3**, 6, 34, 98, 132; 1951, **4**, 697. Crushing is defined very carefully. The basic principles in calculating the work required to obtain a product of the determined dimensions are given. Many practical examples are given and solved.

19. **Progress in Coal Science.** BANGHAM, D. H. 1950, Butterworth. Pt 2. Fine Particles. 456 pp., 40*s*. 0*d*.

20. **Contribution to the Theory of Grinding Processes.** BASS, L. *Z. angew. Math. Phys.*, 15 July 1954, **5** (4), 283–92; *Industr. Diam. Rev.*, Feb. 1955, **12B** 39. Mathematical theory of milling processes are developed by deriving and solving a partial integro-differential equation which describes *time-dependent particle size distribution of milling charge*. This basic equation contains a characteristic function of both mill and material milled, conveniently determined from measurements using an approximation derived from general theory. This approximation, which can also be used independently, can give experimental evidence of validity of general theory. It was established in a previous paper (*Powder Metall. Bull.*, 1953, **6**, 148) that this approximation is in agreement with results obtained by experiments. Several approximate solutions of the basic equation as well as a rigorous one are worked out, and an analysis of the semi-empirical Rosin–Rammler formula is given from the point of view of the present theory. 8 refs.

21. **Broken Coal.** BENNETT, J. G. *J. Inst. Fuel*, 1936, **10**, 22–39. The random fracture of large coal during the processes of mining and handling. It is shown that the residue curves follow the Rosin law over a wide range of particle sizes. The importance of internal fissures is shown. *See under* Coal.

22. **The Relation between Size Distribution and Breakage Process.** BENNETT, J. G., BROWN, R. L. and CRONE, H. G. *J. Inst. Fuel*, 1941, **14**, 111. The mechanical properties can be explained on the view that coal is a brittle material with a random distribution

of internal weaknesses down to the ultimate micelles. This leads theoretically to the Ideal Law of Breakage for the fracture of a single lump by a violent blow. Experimental evidence for Ideal Law is given, and it is also shown to be connected with the fine material or complement produced in mild degradation. Various types of complex fracture are investigated experimentally and lead to generalized laws of size distribution which are shown to be closely approximated by the Rosin–Rammler relation. A distinction is drawn between complete and defective cycles of breakage and it is suggested that this distinction provides a rational basis for the study of breakage processes and the performance of crushing and grinding plant.

23. **The Mechanics of Partial Degradation.** BENNETT, J. G. and BROWN, R. L. *J. Inst. Fuel*, 1941, **14**, 135. The view that coal can be regarded as a brittle material with a random distribution of weaknesses is extended by considering the variability of the weaknesses themselves. This leads to a general law of coal breakage: 'When work is done on a brittle material, the energy appears in part as new surface of fragmented products and in part as the creation of fresh inner weaknesses.' With the help of this law, the mild degradation of a single lump of coal is investigated and relations established between the weight of broken product (complement) and the work W per unit volume, the suddenness factor O which is a measure of the rate of application of the forces, the equivalent number f of points of application of forces and the number p of stages of breakage involved. The changes in the internal weakness of the coal are defined in terms of a History Factor and the relations between this factor and the breakage process examined. A strength index is defined as $B=1/j^{4/3}k$ where j is the fraction of a broken product forming the complement and k the fraction of the complement less than some arbitrary small size. Experimental evidence from shatter tests from a low height, and from tumbler tests, is given in support of the theory.

24. **Grindability and Grinding Characteristics of Ores.** BOND, F. C. and MAXSON, W. L. *Trans. Amer. Inst. min. (metall.) Engrs*, 1939, **134**, 296–323. The authors conclude from a number of trials that: (1) a charge reaches a size eventually where further grinding has no effect; (2) the sole criterion of performance is an examination of the economics of the process. Efficient grinding is that which creates the most surface with least expenditure of energy; (3) in course of grinding, the new surface formed per unit of rotation is constant, whatever the size and size reduction. An impact crushing laboratory machine is described in which a test bar is broken by the falling pendulum at the same time as the sample is crushed. The work for each is calculated from blank determination and characteristics of the machine. On the basis of Rittinger's law, efficiencies in grinding of up to 60% were obtained. [P]

25. **Crushing by Pressure and Impact.** BOND, F. C. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 58; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1895 (8 pp.); *Min. Tech.*, 1946, **10** (1), 58–66. The compressive strengths of 56 Canadian ores are tabulated, the most resistant being chert at 80 000 lb/sq. in. The view is expressed that the standard crushing strength tests are of little use as a guide to resistance in gyratory and ball mills. A better criterion is obtained from resistance to impact. A twin hammer horizontal machine is described in which specimen is held between two anvils and broken by two falling hammers. The impact strengths of 72 materials are tabulated and a comparison is tabulated for crushing and impact strengths of 22 materials, from limestone to taconite. The impact machine was used to calculate joules applied per square meter of new surface. On this basis a ball mill was found to do about 52 joules of useful work in producing new surface out of a total energy input of 93 joules per revolution, that is, an efficiency of 56%. The energy input per square meter of new surface on the impact machine ranged from 289 to 900 joules for 9 materials, ranging from gold ore, cement clinker and pyrites, the hardest. More data are required before the relative merits of compression and impact standards can be decided. Bond refers to Fahrenwald's observation that fines increase with impact crushing.

26. **A New Theory of Comminution.** BOND, F. C. and WANG, J. T. *Min. Engng, N.Y.*,

1950, 2; *Trans. Amer. Inst. min. (metall.) Engrs*, **187** (8), 871–8. The theories of grinding put forward by Rittinger and by Kick are examined and compared. An empirical equation is derived from which the approximate energy input required for any crushing plant can be calculated. Practically all the energy required for crushing is energy of resilience, which deforms the material beyond its elastic limit and is mostly released as heat after breaking or release. A new theory of grinding has been developed—the strain energy theory. According to this theory, the energy required varies directly as $(n+2)(n-1)/n$, where n is the reduction ratio and is independent of the feed or product size; it also varies directly as the square of the compressive strength, and inversely as the modulus of elasticity. According to Kick's theory, the energy requirement is independent of the particle size concerned and is a function of the reduction ratio n. According to this theory it is proportional to $n/\log 2$, whereas according to the strain energy theory it is proportional to $(n+2)(n-1)/n$ or almost directly proportional to n. The derivation of Kick's theory is based on a stage by stage reduction, while the strain energy theory is based on a generalized reduction ratio of any value. The strain-energy theory assigns a greater proportion of the total energy input to the fine size reductions than does Kick's theory, and thus appears to fit the facts more closely. An empirical energy chart is drawn up on a log log scale, showing the energy required to crush and grind many different materials in various types of machine. The plotted data, varying considerably, however, are averaged by three straight lines representing the energy requirements for soft, medium and hard materials, when reduced in machines of increasing energy requirements, that is from jaw crushers to ball mills. The relation is: h.p./ton $= K\sqrt{n \frac{1}{2} p}$, where $n =$ feed size 80% passing and $p =$ product size 80% passing (in inches), $K = 0{\cdot}25$ for soft materials, 0·5 for medium and 1·0 for hard materials. 2 figs, 5 tables.

27. **New Grinding Theory Aids Equipment Selection.** Bond, F. C. *Chem. Engng*, 1952, **59** (10), 169–71. Discusses briefly Bond's third theory, which assumed that the work input necessary to break the rock is essentially that necessary to deform the rock beyond the critical strain and form crack tips. The rock splits without the application of additional energy. Most of this work is transferred to heat when the stress is released. The basic equations involving work index and reduction ratio are given. Laboratory tests to ascertain the work index are described and typical crushing and grinding calculations are given. Dry grinding in tumbling mills requires approx. one-third more power than wet grinding, and fan power on a dry closed circuit is much more than a rake classifier of a wet closed circuit mill. However the metal wear per ton in dry grinding is only about one-fifth that of wet grinding.

28. **The Third Theory of Comminution.** Bond, F. C. *Min. Engng, N.Y.*, 4; *Trans. Amer. Inst. min. (metall.) Engrs*, 1952, **193**, 484–94. After reviewing and criticizing the theories of Rittinger, Kick and Gaudin, the author puts forward 6 requirements for a successful theory. The derivation of the third theory, work index and size distribution of ground product, is explained and the theory then stated: 'The total work useful in breakage which has been applied to a stated weight of homogeneous broken material is inversely proportional to the square root of the diameter of the product particles.' $Wt = K\left(\frac{\mathbf{P}}{P}\right)^{\frac{1}{2}}$, where $Wt =$ work index when $\mathbf{P} = 100$ microns, $P =$ product size at which 80% passes (whether inches or microns), K is a proportionality constant. Examples of practical confirmation are given and extensive tables are presented giving work indices calculated from Allis-Chalmers Laboratory tests and also from data given in Taggart. 11 refs.

29. **Work Indexes Tabulated.** Bond, F. C. *Min. Engng, N.Y.*, **5**; *Trans. Amer. Inst. min. (metall.) Engrs*, 1953, **196** (3), 315–6. A table gives the work indices of 57 classes of material from which the work input (kWh/ton) necessary to reduce the material from infinite size to 80% below a theoretical 100 microns, or 67% below 200 mesh can be calculated. Equations are also given for calculating the work index as a function of

(1) impact crushing strength and specific gravity; (2) rod mill grindability and sieve opening; and (3) ball mill grindability and sieve opening.

30. **Which is the More Efficient Rock Breaker?** Bond, F. C. *Engng Min. J.*, 1954, **155** (1), 82. From data put forward in *Rep. Invest. U.S. Bur. Min.* No. 4918 (Vernon C. Davis), Taconite Fragmentation, June 1953, it is possible to compare efficiencies of breaking, explosive v. machine. From calculations based on work index figures, Bond finds the mechanical efficiencies of breaking by crushing and blasting are approximately equal. Size reduction in an installed crusher costs less than by explosives, since the cost of a kWh in dynamite is far more than a kWh in electricity. But finer quarry breakage by explosives may decrease the size and cost of crusher installation. Although the absolute mechanical efficiencies of rock breaking are still obscure, the evidence favours higher values since it is difficult to believe that the efficiency of planned blasting can be less than 1%. 3 refs.

31. **Volume Changes in Plastic Stages of Compression.** Bridgeman, P. W. *J. appl. Phys.*, 1949, **20**, 1241.

32. **A Matrix Analysis of Processes Involving Particle Assemblies.** Broadbent, S. R. and Callcott, T. G., *Phil Trans. A.* 1956, **249** (960), 99–123. The breakage of a particle assembly is thought of as two processes. Firstly, the machine selects a proportion of the particles for breakage and leaves the remainder unbroken. To discover a function or matrix describing this selection is to understand the machine operation. Secondly, the particle selected is broken in a regular way and the proportion of particles of each size formed by breakage are described as the breakage function or a breakage matrix. The analysis is also extended to classification and return of oversize. Coal breakage has been studied by grinding in a new ball and cone mill, in ball mills and by shutter tests, and is presented mathematically from the above method of analysis. Photos. 14 refs. For later papers *see under* Coal, and Ball and Cone Mill, *and* Open v. Closed Circuit Grinding.

33. **The Brittle Fracture of Pre-cracked Solids.** Brown, R. L. *Research, Lond.*, 1947, **1**, 93. A theoretical consideration of the fracture of pre-cracked solids is shown to suggest a relationship between the shatter strength of equal sized lumps and the sieve analysis of the consignment from which the lumps are taken. Experimental evidence obtained with a friable coking coal is given in support of the theory.

34. **Rational Interpretation of Screen Analysis.** Brown, R. L. *Colliery Engng*, 1948, **24**, 295.

35. **Theory of Grinding.** Budnikoff, P. P. and Nerkritsch, M. I. *Zement*, 1929, **18**, 194–8, 230–3. Discusses conditions that affect crushing efficiency. Gives tensile strength of some minerals. Discusses particle-size determination by sieves and by settling rate, effect of irregular particles on surface measurements, energy necessary for grinding a unit weight of solid to gas which might be assumed as the grinding energy theoretically required, effect of particle size on chemical action and on fusion with the relation of surface thereto, Martin's dissolution method, and Koehler's method of ThO adsorption for surface measurements. As the theoretical efficiency of grinding is so low it becomes advisable to look for other methods of grinding; electric fields of high frequency and waves of high frequency are mentioned as possible means. Using Martin's value for energy required, the efficiency of a ball mill is not above 0·06%.

36. **Matrix Analysis of Machines for Breaking Coal.** Callcott, T. G. and Broadbent, S. R. *Brit. Coal Util. Res. Ass. Document* No. C/4945, 1955. A discussion of mill mechanics leads to the formulation of the theory of breakage processes. The theory is developed in matrix notation which greatly simplifies numerical work. The breakage processes of a new grinding machine, of two ball mills grinding batches of coal, shatter tests of lump coal and the breakage produced by a beater mill have been successfully analysed by the theory.

37. **A Study of Crushing Brittle Solids.** CAREY, W. F. and BOSANQUET, C. H. *J. Soc. Glass Tech.*, 1933, **17**, 384–410. Results of experimental work on the crushing of coal and anhydrite show that under free crushing conditions brittle solids break down with a constant fracture pattern, independent of original size. The work required to crush a powder depends on the product of (a) the constant for the material, (b) the weight of material crushed, and (c) the log of the total mean reduction = log (mean orig. size)/(mean product size), i.e. aperture size. Values indicate that the power actually required is about 100 times the theoretical. Experiments were also done in a crusher adapted for shear crushing. Results are expressed in terms of energy in kWh/ton necessary to cause a reduction ratio of 10.

38. **Crushing and Grinding.** CAREY, W. F. *Mech. World*, 1934, **96**, 413; *Chem. Age, Lond.*, 1934, **31**, 327. Values shown in table indicate that about 100 times as much energy as is theoretically necessary is used. Different methods of applying load, impact or shear make little difference. To crush only the largest particles will lead to the minimum expenditure of power; since otherwise there is overgrinding. It is claimed that overgrinding is responsible for the enormous difference between the 30 kWh/ton required in practice, and the 0·3 kWh/ton in theory.

Crushing constants for various materials kWh/ton

Material	for $R.r = 10$
Felspar	0·354
Black Oxide	0·0185
Flint	0·138
Limespar	0·144
Calcined bones	0·0076
Cement clinker	0·108
Carbide	0·280
Coal	0·05
Anhydrite	0·15

39. **Crushing and Grinding.** CAREY, W. F. *Trans. Instn chem. Engrs, Lond.*, 1934, **12**, 179–84. Previous work is continued. Compression tests on single pieces, free crushing, and on beds of materials are described, including crushing roll experiments. It is shown that the various stages of crushing produce a constant fracture pattern, and the crushing energy required to produce a reduction ratio of 10 is calculated for a large number of materials.

40. **Development of a Centrifugal Ball Mill.** CAREY, W. F., ROBEY, E. W. and HEYWOOD, H. *Engineering, Lond.*, 1940, **149** (3874), 378. An attempted design of a mill for 'free crushing'. *See under* Centrifugal Ball Mill, No. 1324.

41. **Energy Flow Sheet of Milling Practice.** CAREY, W. F. and HALTON, E. M. *Trans. Instn chem. Engrs, Lond.*, Nov. 1946, **24**, 102–8. Over 99% of the energy used in milling systems is dissipated in heat. Heat balances are tabulated for various kinds of ball mill to show the proportions which went to heating the air, evaporating water, to the product itself and to ambient losses. The dissipation of strain energy is discussed and the conclusion is drawn that whether the energy of fracture is regarded as 1% or 0·1% of the energy input, it is very difficult to measure accurately and would not greatly influence mill design. *See also Chem. & Ind.* (*Rev.*), 1947, (2), 29–30. [P]

42. **A Method of Assessing the Grinding Efficiency of Industrial Equipment.** CAREY, W. F. and STAIRMAND, C. J. *Recent Advances in Mineral Dressing*, 1953, 117–36. Institution of Mining and Metallurgy. The authors have applied the concept of free crushing to the determination of the energy requirements for crushing small, sieve graded particles between iron plates under free crushing conditions, the conditions being assumed to be the best possible. Although the speed of compression may be

from 10 to 10 000 times less than the normal impact speeds, in view of the economy of effort in slow crushing, the results of this laboratory method are regarded as a sound basis for estimating the efficiency of industrial operations. The mechanical efficiency of a normal grinding operation is equal to: $(EP-EF)/EM$. EP and EF are the energies associated with product and feed respectively, as determined from free crushing tests under compression. EM is the observed energy used by the mill being tested. Results are shown for coal (6·0%) ground in a ball mill, and for quartz (15 and 35%) ground in a ball mill and hammer mill respectively. The method of calculation of associated energy at various sizes is explained. The application of the Kick and Rittinger laws, although still holding the field as a basis for calculating energy requirements, possesses little or no advantage over empirical methods, that is, simple assumptions that 3–4, 5–6, 20–30, 100–1000 kWh/ton suffice for coarse and intermediate crushing, fine grinding and superfine grinding respectively. An Appendix shows the method of predicting the power required to rotate a ball mill.

43. **The Calculation of the Comparative Efficiencies of Crushing and Grinding Machines.** CHAPMAN, R. W. *Proc. Aust. Inst. Min. Engrs*, 1909, 4 (4), 215; *Trans. Aust. Inst. Min. Engrs*, 1909, **13**, 154–7. The author gives formula used by Klug and Taylor (*Mon. J. Chamb. Min. W. Aust.*, 31 Jan. 1906). Work done in grinding is proportional to Qx^2/y^2, where x and y are the original and final diameters resp. Chapman substitutes for this: work is proportional to $Q(n-m)$, where m and n are the original and final mesh size resp. Gives examples, but does not consider material finer than 200 mesh. Abstract in *Mines & Minerals*, Feb. 1910, 413–4.

44. **Exploitation of Low Grade Ores in the United States.** CHARLES, R. J. *O.E.E.C. Technical Assistance Mission* No. T.A.W/228/(55).1, O.E.E.C., Paris; Doctor's Thesis. Massachusetts Institute of Technology, 1955. Impact studies on fixed end rods. Research in the field of impact crushing is going on at M.I.T., concerning the medium of the transfer of kinetic energy of an impacting object to strain energy in an impacted piece. For theoretical reasons, and also on account of experiments reported by Johnson, Axelson and Piret, *Chem. Engng Progr.*, 1949, **115** (12), 713, the strain energy absorbed by particles during crushing is directly proportional to the new surface formed. It may be said that the mass of the impacting object, according to Charles, must stand in a certain relation to the mass of the impacted piece for a maximum transfer of the kinetic energy into strain energy.

45. **High Velocity Impact in Comminution.** CHARLES, R. J. *Min. Engng, N.Y.*, 1956, **8** (10), 1028–32. Pyrex glass cylinders were broken on an anvil by falling heavy weight at low velocity and by an air-gun projectile at high velocity. The conclusions to be drawn from results of experiments are: (1) High velocity impact produces fracture at lower energy than low velocity impact. The number of failures out of ten tests increases from 0 at 170 kg cm to 10 at 50 kg cm at low-velocity impacts, whereas all 10 specimens are fractures by the equivalent high-velocity impacts. (2) When fracture is actually obtained, energy applied by low velocity or compression loading produces a larger size reduction than the equivalent energy at high velocity. (3) The mode of fracture, i.e. the slope of the distribution curve, is determined by the manner of loading. (4) Shattering by high-velocity impact produces a closer sized product than shattering by low-velocity impact. Distribution curves show a much higher slope for high- than for low-velocity impact. They also show the increasing fineness as energy of impact increases, and a very marked displacement towards the finer sizes for low-velocity impact, although for the latter, the slope is less, i.e. the spread of sizes is greater. Photographs, 4 refs.

46. **Chemistry of Fine Grinding.** CHWALA, A. *Kolloidchem. Beih.*, 1930, **31**, 222–90. A long comprehensive paper on the properties of fine powders. Various mills are described and sedimentation properties of powders are discussed. Data and graphs.

47. **Grinding Tests for Easy Interpretation of Results.** COGHILL, W. H. and DEVANEY,

F. D. *Rep. Invest. U.S. Bur. Min.*, No. 3239, 1934. Grinding studies are of two kinds: (1) character of the ore, and (2) performance of machine. (1) Size distribution and grindability, work transformed to new surface. (2) Performance of machine is compared by size distribution of products, using drop weight tests. It is suggested that for grindability, there should be equal amounts through a 200-mesh sieve, but for grinding characteristics there should be equal size distribution analysis.

48. **Evaluating Grinding Efficiency by Graphical Methods.** COGHILL, W. H. *Engng Min. J.*, 1928, **126**, 934–8. Uses 'force diagram' to obtain 'mean mesh' as a measure of advance in a crushing operation. By sieve sizing and surface figures based on size of particles the power efficiency is measured. Minus 200-mesh material is considered as unnecessary work, and the machine should not be credited therefore. Counts on sieve sizes of chert and dolomite from 2-mesh to 60- or 65-mesh check with theoretical number of particles; therefore, similar shapes exist in all sizes, and a surface figure in proportion to the theoretical for all sizes is allowable.

49. **Investigations in Ore Milling to Ascertain the Heat Developed in Crushing.** COOK, J. *Trans. Instn Min. Metall., Lond.*, 1914–15, **24**, 234–51. Measurement of energy input to stamps from weight and drop. Increase in temperature of pulp accounted for 80% of the energy. Accounts for other 20% as guide friction, sound vibration, radiation, energy (velocity) of pulp through screens, deformation of malleable particles, surface energy, and electrical energy. In the discussion, R. S. Willows considers surface and electrical energy as a result of crushing which would not affect temperature.

50. **Big New Plants High-Light Beneficiation Development.** CRABTREE, E. H. *Min. Engng, N.Y.*, 5; *Trans. Amer. Inst. min. (metall.) Engrs*, 1953, **196** (2), 158–9. A short section appraises Bond's third theory as a real contribution. It has now been extended to cover economics, metal wear, dry v. wet grinding, volume of grinding charge, pulp dilution, mill speeds, grinding media sizes, and mill diameter. Myers is quoted as saying that Bond's third theory will be regarded twenty years hence as the turning-point in understanding of what controls comminution. The Bond theory clearly shows the weakness of our grinding circuits in vogue today. The relation of the theory to present day classification is also referred to.

51. **Taconite Fragmentation.** DAVIS, V. C. *Rep. Invest. U.S. Bur. Min.*, No. 4918, 1953. From the data in table 10 and figs 97 and 119, Bond, *Engng Min. J.*, 1954, **155** (1), 82, compares the efficiencies of explosion and machine breakage.

52. **Measurement of Crushing Resistance of Minerals by the Scleroscope,** DEAN, R. S., GROSS, J. and WOOD, C. E. *Rep. Invest. U.S. Bur. Min.*, No. 3223, 1934, 33–5. It is pointed out that the zone of deformation for metals becomes a zone of fracture for brittle materials, and the energy absorbed may be used as a measure of resistance to crushing. The method of making the test is described and it is shown that the figure for energy absorbed when plotted against the weight of material crushed per unit of work, gives a straight line relationship.

53. **Magnetite as a Standard Material for Measuring Grinding Efficiency.** DEAN, R. S. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 660, 1936. 5 pp. *See under* Magnetic Effects.

54. **Mechanical Efficiency in Crushing.** DEL MAR, Algernon. *Engng Min. J.*, 1912, **94**, 1129–34. Determines the grinding efficiency on Nissen, and gravity stamps, and on two grinding mills by: (1) Surface figures (reciprocal of size $\times$ percentage) taking -120 mesh (the last sieve size) as equal to -120×150 mesh, and (2) Stadtler's figures for Kick's law. By these two methods the efficiency of the Nissen and gravity stamps are about the same, but for the two grinding mills the reverse results are obtained. The comparison suffers by reason of the absence of analysis of the sub-sieve particles.

55. **Development of the Science of Grinding.** DJINGHEUSIAN, L. E. *Trans. Canad. Min. Inst. (Inst. Min. Metall.)*, 1952, **55**, 374–82; *Canad. Min. Metall. Bull.*, 1952, **45**, 658–63; discussion 664. The work of present-day investigators is submitted as grinding criteria.

These comprise: (1) power; (2) grindability; (3) 80% passing n. mesh; (4) total work input; (5) Bond's work index as a measure of comparative grinding efficiencies; (6) work index as a function of grindability; (7) grindability as a function of '80% passing'. In the last section the concept of thermodynamic criteria in grinding is offered. This concept is not a new one, having already been advanced by some of the previous investigators. However this concept is offered as a mathematical law, with the hope that its analysis and criticisms by grinding investigators will finally lead to the laws of grinding resting on scientific rather than empirical methods. 19 refs.

56. **The Influence of Temperature on Grinding Efficiency.** DJINGHEUSIAN, L. E. *Dept. of Mines and Technical Surveys, Canada, Res. Rep.* No. M.D.138, 2 March 1953, 62 pp. Summary and conclusions. (1) High temperatures increase absolute mechanical efficiency of grinding. (2) For a given set of circumstances, there is a fixed time of contact, for maximum grinding efficiency. (3) For given conditions, efficiency of grinding is a function of the size of feed. (4) Reduction of quartz is practically unaffected by temperature. No 'constant fractions' could be obtained in grinding quartz. (5) In grinding certain ores it was indicated that the relationship between mechanical energy expended per sq. cm of new surface produced and Bond's work index is a straight line, thus indicating the validity of '80% passing'. (6) Part of the heat applied externally or developed is transformed into useful work. The research is being continued with a view to clarifying the concept that absolute mechanical efficiency of grinding is a function of the internal heat energy of the material. Graphs, illustrations.

57. **The Influence of Temperature on the Efficiency of Grinding.** DJINGHEUSIAN, L. E. *Trans. Canad. Min. Inst. (Inst. Min. Metall.)*, 1954, **57**, 157–68. *Canad. Min. Metall. Bull.*, 1954, **47** (504), 251–62. From a series of investigations into the relation between power consumption and temperature of the pulp in a ball mill, the author concludes (1) that at higher temperatures, the mechanical efficiency of grinding increases, (2) for every temperature at given conditions, there is a fixed time of contact at which grinding efficiency is at its maximum; (3) quartz behaved differently from other rocks; (4) the results prove the validity of Bond's third law of comminution; (5) part of the heat applied externally or generated in grinding in an insulated mill is transformed into useful work, this being in agreement with the second law of thermodynamics. For differences of temperature of about 20°F, the percentage new surface increased by from 6 to 19. A large amount of useful data is tabulated for the grinding of various ores under controlled conditions. 7 refs.

58. **Abrasion Resistance and Surface Energy of Solids.** ENGELHARDT, W. von. *Naturwissenschaften*, 1946, 33, 195–203; *Brit. Abstr., A*, 1947, 204. Products of abrasion, e.g. from grinding wheels, and surface formation in relation to energy consumption are discussed. A quantitative treatment is attempted. The effect of discontinuities in the structure of quartz is discussed and the effects of various fluids on resistance to abrasion and crushing are determined. Considerable differences in effect are found. Results are presented in tabular and graphic form. 23 refs.

59. **Ball Mill Studies. II. Thermal Determinations of Ball Mill Efficiency.** FAHRENWALD, A. W., HAMMAR, G. W., LEE, H. E. and STALEY, W. W. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 416, 1931. 13 pp. Since the calculated surface energies for quartz as calculated by Edser and Martin were widely different and probably both too low, it was desired by the author to use a method for efficiency determinations which would dispense with surface data and surface energy. Efficiencies based on thermal experiments were 7% and 20% as compared with 0·6% and 1·2% respectively when based on surface energy of 510 and 920 ergs/sq. cm (for quartz). Efficiencies from thermal experiments were found to be less with wet grinding. Fahrenwald stated that a useful step forward in the study of efficiencies was made when Martin and Gross proved the correctness of Rittinger's law.

60. **Velocity of Hit in Rock Crushing. Pts. 1 and 2.** FAHRENWALD, A. W., NEWTON, J.

and HERKENHOFF, E. *Engng Min. J.*, 1937, **138** (12), 45–8; 1938, **139** (1), 43–6. Results with a roll crusher were not satisfactory and were abandoned in favour of drop weight tests. It was found with the latter that the rate at which energy was imparted to the particle has a large influence on the nature and extent of crushing. A light high-velocity blow does more crushing than a heavy low-velocity blow of the same kinetic energy and produces a product of more uniform size. As the velocity increases the maximum of the distribution curve moves towards the finer sizes. Very high velocities tend to produce very large amounts of fines. Ottawa sand was used for the experiments.

61. **A Method of Predicting the Performance of Commercial Mills in the Fine Grinding of Brittle Materials.** FAIRS, G. Lowrie. *Bull. Inst. Min. Metall., Lond.*, 1954, **63** (5), 211–40. A method is described for predicting the performance of a series of commercial grinding mills: 10-in. batch ball mill; swing hammer screen discharge mills, coarse and fine; fixed beater air attrition mill with static classifier, the reduction being assumed to be mostly by attrition between particles. The results over a range of operating conditions were compared with those obtained from a laboratory impact crusher (vertical with soft metal support) operating under free crushing conditions, and in each case the net energy input to new surface relationship was found to be linear except for later stages in the run of the batch ball mill where the curve turned towards the energy axis. The plots pass through the origin and the gradients of the lines give a measure of the efficiencies of the mills. The relative mill efficiencies are in the same ratio for the three brittle substances examined, i.e. limestone, barytes and anhydrite. The ratios of the fineness indices, i.e. sq. cm/g of ground product are the same for the series in the case of each material. This means that given a laboratory test on a unit impact crusher for a new brittle material, the energy to surface ratios and the order of fineness can be predicted therefrom for commercial mills in the series. For rock salt which is subject to plastic deformation, the linear relationship was found but the relative performances of the mills were not in the same order as with the other materials. Rock salt becomes hygroscopic. Efficiencies of grinding were determined on the basis of associated energies, i.e. energy to surface relationships compared with the unit crusher:

Swing hammer mill, coarse .	20–30%
Swing hammer mill, fine .	5–10%
Ball mill	10–13%
Air attrition mill . . .	4%

The author tabulates data for 7 mills with the four materials already used, to show how observed efficiencies ranging from 4 to 88% compare with those calculated from theoretical surface energies. He also tabulates the sources of information and methods for surface energy calculations for the four materials to show the enormous variation from various sources, and how this variation in the case of rock salt, from 77 to 3560 ergs/cm, can affect the theoretical efficiency of mills, 0·5–32%. The usual theoretical efficiency however is less than 1%. (Permeability method was used for surface area.)

62. **The Crushing Surface Diagram.** GATES, A. O. *Engng Min. J.*, 1913, **95**, 1039–41. Discusses both Rittinger and Kick laws, the use of crushing surface diagram for crushing results, cyanide extractions, and cement plant work. Calls attention to the large part that −200 mesh material plays.

63. **Applications of the Crushing Surface Diagram.** GATES, A. O. *Engng Min. J.*, 1914, **97**, 795–800. Its use to depict the action of various crushing devices and the effect of leaching in cyanidation and in cement and concrete is described.

64. **An Investigation of Crushing Phenomena.** GAUDIN, A. M. *Trans. Amer. Inst. min. (metall.) Engrs*, 1926, **73**, 253–316. Deals in a comprehensive manner with the size distribution curves for products from crushing rolls and ball mills. The work was undertaken to condense information into rules which would be of use in developing

a theory; the following conclusions appear justified: (1) rocks may be classified into homogeneous and heterogeneous materials; (with the former, fracture takes place through grains and grain boundaries); (2) if a sized homogeneous material is crushed, the size distribution of the product follows a definite law; (3) ball milling of homogeneous rocks can present exceptions to rule 2; (4), (5), (6) deal with the critical ratio of feed to ball size and the effects on size and shape of grains, when this ratio is departed from in ball milling; (7) different methods of crushing produce grains of different shapes; (8) the importance of sizing the −200-mesh portion of a crushed product in crushing efficiency investigations, has been greatly underestimated. Discussion. Graphical representation of experimental results in size analysis. Comparative tests between bench and large-scale tests have given efficiencies from 6 to 25%.

65. **Principles of Comminution—Size and Surface Distribution.** GAUDIN, A. M. and YAVASCA, S. S. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1819, 1945. An experimental determination of the surface factors of glass, galena and pyrite has been made. The crushed samples were screened, cleaned with HCl soln. washed with distilled water, dried and examined under the binocular microscope. The results in all cases show that in the fine sizes (i.e. 30 I.M.M. and upwards), the area of the new surface obtained by grinding is the same in each grade, i.e. sieving grade. This agrees with previous experiments on quartz. See *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1779, Nov. 1944, by Gaudin.

66. **Principles of Mineral Dressing.** GAUDIN, A. M. 1939, McGraw-Hill Publishing Co. In Chapter 6, the author has precisely stated the amplified form of Rittinger's theory: 'The efficiency of a comminution process is the ratio of the surface energy produced to the kinetic energy expended.' Computations using the best available values for surface energy indicate that perhaps 99% of the work put in is wasted.

67. **Micro Indentation Hardness. A New Definition.** GRODZINSKI, P. *Industr. Diam. Rev.*, 1952, **12**, 143, 209–18. The defects of present hardness definitions are discussed and a new definition is suggested, i.e. that hardness be defined as the load which causes a deformation of unit length or depth. A special apparatus is suggested and correlation with conventional hardness formula has been calculated.

68. **Efficiency of Grinding Mills.** GROSS, J. and ZIMMERLEY, S. R. *Rep. Invest. U.S. Bur. Min.*, No. 2948, 1929. Gives the crushing resistance of galena, sphalerite, pyrite and calcite in relation to quartz, based on surface produced under accurately measured work input. [P]

69. **Efficiency of Grinding Mills.** GROSS, J. and ZIMMERLEY, S. R. *Rep. Invest. U.S. Bur. Min.*, No. 2952, 1929. 23 pp. Gives method for determining surface on ore by comparing sieve sizes and elutriation products with quartz, surface of which has been determined. Results given show over-all and useful efficiency of ball mills. Gives classifier efficiencies and discusses −200-mesh material. A large proportion of work goes to useless grinding.

70. **Crushing and Grinding. I. The Surface Measurement of Quartz Particles.** GROSS, J. and ZIMMERLEY, S. R. *Trans. Amer. Inst. min. (metall.) Engrs*, 1930, **87**, 7. The rate of solution of surface in hydrofluoric acid is determined by extrapolating the curve–time v. quantity dissolved–to zero time. Surface measurements were also made by coating the particles with silver, the quantity being measured then by chemical means. The surface as determined by silvering was found to be 1·3 times the calculated spherical surface for water-worn Ottawa sand.

71. **Crushing and Grinding. II. Relation between the Measured Surface of Crushed Quartz to Sieve Sizes.** GROSS, J. and ZIMMERLEY, S. R. *Trans. Amer. Inst. min. (metall.) Engrs*, 1930, **87**, 27. The surface determinations of closely graded fractions of crushed sand by the various methods are summarized for two extreme sizes. For 150/200 mesh size the solution and silvering methods gave 2·1 and 1·9 times respectively the value

for spheres. For ¼-mesh size the values were 8·5 and 2·4 times the value for spheres, respectively. It is concluded that the silvering method is the more accurate and that the solution method includes internal surface of the particles.

72. **Crushing and Grinding. III. Relation of work Input to Surface Produced in Crushing Quartz.** Gross, J. and Zimmerley, S. R. *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1930, **87**, 35. Impact tests were made on 10–14- and 20–28-mesh fractions of crushed quartz, the energy not actually absorbed in crushing being measured by the deformation of three pieces of aluminium wire supporting the anvil. The height of rebound of the impacting steel ball was also used as a measure of the excess energy. Rate of solution method was used to measure surface area. The increase was found to be close to 17·5 sq. cm/kg cm for various intensities of impact. This represents an efficiency of 3%, if based on Edser's figure for the surface energy of quartz of 920 ergs/sq. cm.

73. **A Device for Determining Work Input to a Laboratory Mill.** Gross, J. and Zimmerley, S. R. *Rep. Invest. U.S. Bur. Min.*, No. 3056, 1931. A simple type of torsion dynamometer is described, for measuring the power input to a small ball mill. The torque is measured by the extension of three springs placed between two discs, one on the mill shaft and the other on the driving shaft. The speed factor is measured by a differential integrating meter. The two meters are combined to give a direct reading of the power to the mill. Details of design are given.

74. **Summary of Investigation on Work in Crushing.** Gross, J. *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1934, **112**, 116. Within the last few years study of the energy used in crushing has advanced from perplexing confusion to greater clarity. The Rittinger theory that energy required in successive steps in reduction increases geometrically appears to be established. There are still needed a simple direct method of determining surface on a crushed product, a simple and accepted elutriation or sedimentation test for −400-mesh material and investigation of new means of accomplishing comminution. It is considered that the energy required to produce fracture will be less with rapidly applied loads, and references are made to the advantages of explosive shattering. 128 refs.

75. **Crushing and Grinding.** Gross, J. *Bull. U.S. Bur. Min.*, No. 402, 1938. 148 pp. Although crushing and grinding machinery has been brought to a high pitch of development mechanically, corresponding advance has not been made in regard to theory and the conception of underlying principles. This lack of advance in theory may be attributed to the unfortunate situation resulting from the controversy as to whether the Rittinger or the Kick law is applicable to crushing. Many pages of the technical literature are devoted to theoretical discussions in favour of one or the other of these laws, which have tended to cloud rather than to clear the atmosphere. It was realized by various bodies in the U.S.A. that a thorough study of the laws of crushing was of the highest importance and in 1924, the U.S. Bureau of Mines inaugurated investigations on crushing at its Intermountain Experimental Station at Salt Lake City. The results of the earlier part of this work, carried out by S. R. Zimmerley, S. J. Swainson and J. Gross, have been published at various periods, but are reviewed in the present paper, with additional comments warranted by subsequent developments. The Bulletin discusses the theory of crushing and grinding in relation to present-day discoveries and developments and considers the various appliances from a theoretical basis. In regard to the Kick v. Rittinger controversy, it is pointed out that the work of the U.S. Bureau of Mines and of G. Martin, in which surface determinations of the crushed materials confirmed the Rittinger law, would seem to be final. The subject matter is dealt with under 13 main headings. 142 refs.

76. **The Distribution of Energy in Crushing.** Hancock, R. T. *Min. Mag., Lond.*, June 1932. Discusses the work of other investigators on the energy consumed in crushing.

77. **Effects of Grindability on Particle Size Distribution.** HARDGROVE, R. M. *Trans. Amer. Inst. chem. Engrs*, 1938, **34**, 131; *Ceramic Abstr.*, 1940, **19**, 20. Knowing the grindability and specific gravity, an approximate estimate of the surface area can be made for a given screen size. *See under* Grindability.

78. **Single Crystals Without Dislocations.** HARDY, H. K. *Research, Lond.*, 1955, **8** (2), 57–60. Strength of 'whiskers' of pure metals. *See under* Mechanism of Fracture.

79. **A Contribution to the Kick *versus* Rittinger Dispute.** HAULTAIN, H. E. T. *Trans. Amer. Inst. min. (metall.) Engrs*, 1923, **69**, 183–97; *Bull. Univ. Toronto Sch. Engng Res.*, 1924, (4), Sect. 4. Gives experiments made in rolls which show that most of the energy required in rock crushing appears as heat, but surface formation itself does not generate heat. Doubtless the energy absorbed in the formation of surface is in accord with the Rittinger law, and the heat must be due to friction. Energy curves, plotted according to Rittinger and Kick, do not check with the actual energy, and a new formula is proposed. Results are based on sieve sizing, assuming a figure for −200 mesh of approximately 35 microns average size. 'The energy required for the actual process of crushing (disregarding losses in the machine itself) is absorbed mainly in three ways: (1) Actual formation of new surface or final rupture; this is a small part of the total energy. (2) Internal friction accompanying the distortion prior to rupture. (3) Surface friction of particles on particles and of particles on crushing surface.'

80. **Particle Size and Work of Division of Materials in the Three States of Aggregation.** HENGLEIN, F. A. *Chemikerztg*, 1944, **68**, 23–5. Assuming that the physical work (Ap) involved in subdividing any material equals the increase in its surface energy, the value of Ap for liquids and gases, compact solids of any shape, and porous solids can be expressed by $[(1/d_2)-(1/d_1)]fs/by$, where d_1 and d_2 are the initial and final particle diameter or length of edge, s is the mean sp. surface energy, y the sp.gr., f a const. factor dependent on the particle shape (6 for spherical or cubic particles), and b is a porosity factor (1 with zero porosity).

81. **The Status of Research on Ore Dressing.** HERSHAM, E. A. Report to the Milling Committee of American Institute of Mining and Metallurgical Engineers and U.S. Bureau of Mines, 1923. A complete report on the needs for further research in crushing and grinding.

82. **Measurement of the Work in Crushing.** HERSHAM, E. A. *J. Franklin Inst.*, 1923, **196**, 95–104. Voices need for a means of determining the accomplishment in crushing and plea for the Rittinger law. Stresses the necessity of measuring heat.

83. **Review of the Literature on the Grinding of Coal.** HEYWOOD, H. *Combustion Appliance Makers Association Document* No. 1657, 1938. 122 literature references are annotated and classified, and prefaces are given to the five main sections. A large proportion is reproduced in the present bibliography. C.A.M.A. has now given place to the British Coal Utilization Research Association.

84. **Application of Sizing Analysis to Mill Practice.** HEYWOOD, H. and PRYOR, E. J. *Bull. Inst. Min. Metall., Lond.*, 477, 1946, 18 pp. A particle tends to slide on its broadest area rather than present a minimum cross-section to a screen, and consequently particle shape is a determining factor in screen efficiency. As a result of many shape measurements it is permissible to assume that many particles may be represented by a mean shape, with a length to breadth ratio 1·2 to 1·5:1·6 to 1·8. A table gives the surface area per gram of material for 150–200-mesh screened fraction, from which is deduced the amount of energy required to produce any size of particle. Grinding efficiency has been improved by the study of ball-ratio, closed circuits, control of classifier and mill density, speed of mill, dwelling time in the mill etc. Laboratory techniques used in sizing are screening, wet and dry, and equivalent sieves. Difficulty is encountered with the former method with near-mesh particles, and in the latter case fine particles are sometimes designated by an equivalent sieve mesh which it is

impossible to manufacture in fact. Methods of determining sub-sieve surface measurement are indicated, although not in detail. Laboratory control in a mill is needed to indicate day to day consistency. The weakest link in the sampling chain is the human element, and hand work should be reduced to a minimum. In sizing analysis the sub-sieve composition can provide an important controlling factor in relation to grinding cost and concentrator efficiency. While the constituency of a mill pulp remains largely unknown as regards fractionation, an important variable will continue to escape control. The author presents a table giving the distributions by weight and size of ground silica in comparison with surface area for the fractions. Data for particles below 2 mu were found by extrapolation, Rittinger's law being assumed. Four types of energy loss in large scale grinding are: mechanical, heat, overgrinding and by unrecorded development of cracks.

85. **Some Notes on Grinding Research.** HEYWOOD, H. *J. imp. Coll. chem. Engng Soc.*, 1950–1–2, (6), 26–38. The relation of crushing tests to the primary and secondary (and possibly tertiary) size components of the product is discussed and illustrated. The relation between time of grinding and energy surface relationship is discussed, current views on energy balance are presented, and certain research needs are put forward.

86. **Principles of Crushing and Grinding.** HEYWOOD, H. *Chemical Engineering Practice*, Vol. 3, Chap. 1, pp. 1–23. Butterworths Scientific Publications, 1957. Theories of the mechanism of crushing and grinding. 34 refs.

87. **Fundamental Laws of Pulverizing.** HOENIG, F. *Forschungsh. Ver. dtsch. Ing.*, 378, 1936 (20 pp.); *Engng Abstr.*, 1936, **69**, 44. Discusses the Kick and Rittinger laws and surface irregularities in relation to measured surface. The various methods of testing the strength of materials, the order of effectiveness of the methods and the effect of the material structure are considered and experimental work in support of theories is described. A summary of the results of experiments on compression and impact tests on crude and calcined magnesite, granite and basalt shows that the actual energy of crushing is intermediate between the requirements of Kick and Rittinger law.

88. **Grinding Investigations on Cement Mortar and Brick.** HOENIG, F. *Verfahrenstechnik*, 1937, (1), 21–6. After referring to the difference between the physical and the mechanical energy required and used for breaking, investigations on cement and brick cubes are described, in which the influences of amount of work applied, the weight of the falling hammer, and mechanical composition, on the results of crushing are separately determined. It was found that at the same total energy a smaller weight from greater height had a slightly greater crushing effect than the reverse, but no significant difference was observed between the results of pressure crushing and 10 and 15 kg cm/cu. cm blows. While the cementing material was affected by the smaller impacts, the quartz grains were affected by the larger impacts. For the two materials tested, the results bore out the Rittinger law. In 1936 the author (*Forschungsh. Ver. dtsch. Ing.*, 378) had found that the results from hard materials such as granite, basalt, supported Kick's law. (The finest product from the cement mortar was of course that of the sand particles used.)

89. **On the Rupture of Iron by a Blow.** HOPKINSON, J. *Proceedings of the Manchester Literary and Philosophical Society*, 1872, **11**, 40–5; *Collected Science Papers*, 1901, **2**, 316–9, Cambridge University Press. From experiments on the breakage of elastic iron wire by a falling weight attached to one end and allowed to drop, the author inferred that breakage does not depend on the mass, and demonstrated that original impact stress depends on impact velocity.

90. **Functions of Granulometric Analysis.** HUTTIG, G. F. *Mh. Chem.*, 1953, **84** (2), 272–7. The results of granulometric analysis are presented as six functions of grinding. These are: throughput characteristic, frequency, mill flow, reduction movement, milling characteristic, formation characteristic. The application of statistical mechanics

to grinding processes is discussed and emphasized. *See also* Plenar Vortrag auf dem Europaischen Treffen für Chemische Technik. Frankfurt am Main. 21 May 1952.

91. **The Significance and Interpretation of Comminution Procedure and Size Distribution.** HUTTIG, G. F., EBERSOLD, W. and SALES, H. *Radex Rdsch.*, 1953, **9–11**, 489–93. A series of functions is determined, based on sieve analysis, from which the characteristic qualitative and quantitative features of the grinding process are evaluated. In the case of quartz sand, the mechanism of 'fragmentation' prevails, while for talc the mechanism of abrasion is dominant. A simple formula is put foward to express the relative probability of a particular size in a ground product: $H=dD/dx=f(x)$, where D = passing characteristic, x = particle size, H = probability factor.

92. **The Grinding of Powders.** JAGER, F. *Tech. mod.*, 1947, **39**, 357; *Chem. Abstr.*, 1948, **42**, 1767; *Build. Sci. Abstr.*, 1948, **21**, 132; *Rev. gén. Caoutch.*, 1948, **25**. (1) Study of crushing by slow pressure with an Amsler 100-ton machine. (2) Grinding by ball mill. The slow application of high pressure with a 100-ton Amsler machine to sand or cement in a cylinder further decreased the particle size, and more efficiently than by normal milling methods. The effect on the compressive strength of cement is discussed. Tests with 2·6 kg steel balls falling through 1–2 metres indicated that maximum instantaneous average pressures of 23 000–28 000 kg/sq. cm were reached at the contact with a flat steel plate. It is concluded that present methods of crushing could be improved by progressive crushing and not by impact.

93. **Deformation and Strength of Crystals.** JOFFE, A. *Z. Phys.*, 1924, 286–302; Proceedings of the International Congress on Applied Mechanics, Delft, 1924, 64. Working with single crystals of rock salt, the author found that the ultimate strength when tested in air at room temperature was only 45 kg/sq. cm. If a similar specimen is tested in hot water, it reaches a yield point at a stress of 80 kg/sq. cm, and then stretches plastically, finally fracturing at a stress of 16 000 kg/sq. cm, which is not far from the theoretical strength of 20 000 kg/sq. cm as calculated by F. Zwicky, *Phys. Z.*, 1923, **24**, 131. These experiments demonstrated that the smoothing effect upon the surface of the test piece has a great effect on tensile strength. X-rays were used for the observations of structure. *See also* King and Tabor *under* Mechanism of Fracture.

94. **A Study of Reduction by Roller Mills.** KHUSID, S. D. *C.R. Acad. Sci. U.R.S.S.* (*Dokl. Akad. Nauk S.S.S.R.*), 1953, **88**, 449–52; Translation by O.T.S., U.S. Dept. Commerce, *Tech. Rep.* No. 22. The deformation of particles between serrated rollers and the character of the resulting product is studied and illustrated.

95. **Contribution to the Knowledge of the Mechanics of Soft Materials.** KICK, FR. and POLAK, F. *Dinglers J.*, 1877, **224**, 465–73. A pictorial, geometrical and short mathematical analysis of the deformation of soft bodies under load. It is concluded that the law of deformation is the same for all those bodies in which the particles can be made to slide or flow under pressure. The main difficulty encountered in proving this thesis is the attainment of similarity and uniformity in the specimens to be tested. *See* Atomic Energy Research Establishment Library Translation 738, 1956, by F. Hudswell.

96. **Contribution to the Knowledge of the Mechanics of Soft Materials.** KICK, FR. and POLAK, F. *Dinglers J.*, 1879, **234**, 257–65, 345–50. The authors have formulated a law, based on experimental evidence, which states that the amount of deformation is proportional to the energy applied. They then show that the pressure required for similar deformation of similar shaped bodies of similar material is proportional to the cross-section area of these bodies. A geometrical analysis is presented with deformation diagrams. *See* Atomic Energy Research Establishment Library Translations 739 and 740, 1956, by F. Hudswell.

97. **Contribution to the Knowledge of Brittle Materials.** KICK, FR. *Dinglers J.*, 1883, **247**, 1–5. Following previous work, the law already enunciated for the deformation of

soft materials is now shown to embrace the fracture of hard materials. Evidence is obtained from the results of experiments on the energy required for fracture (by falling weight) of stone and cast iron pellets or balls and of glass spheres and cylinders. *See* Atomic Energy Research Establishment Library Translation 741, 1956, by F. Hudswell.

98. **The Law of Proportional Resistance and its Application to Sand and Explosions.** KICK, Fr. *Dinglers J.*, 1883, **250**, 141–5. Kick's law is again enunciated. The amount of deformation or fracture of materials similar in physical properties and shape is proportional to the amount of work applied. The law is based on experimental evidence, and single specimens are referred to. The extension of the law to the deformation of sand heaps by applied loads and of the deformation of materials by explosives is demonstrated in the present paper. *See* Atomic Energy Research Establishment Library Translation 669, 1956, by F. Hudswell.

99. **Recent Results of Fine Grinding.** KIESSKALT, S. *Z. Ver. dtsch. Ing.*, 11 Oct. 1955, **97** (29), 1009–11. From experiments with a model ball mill, and with determinations of friction and lifting fractions of the input energy to the charge, it is found that the 1867 Rittinger law for energy input based on the weight of the material is not valid. For brittle materials, it is demonstrated that the energy input is in proportion to the square of the specific surface.

100. **Mining and Dressing of Low Grade Ores.** KIHLSTEDT, P. G. *O.E.E.C. Technical Assistance Mission*, No. 127, 1952, O.E.E.C., Paris. Obtainable from H.M. Stationery Office. In the discussion of M. Murke's paper at the Swedish symposium, Prof. Kihlstedt regarded his own 'classification quotient' $K=K_{90}\times S$ as a measure of the coarseness of the product, K being a dimensionless figure equal to the specific area in cm^2/cm^3 multiplied by the particle size at 90% passage in cm. It actually represented the ratio between the maximum sizes and the average sizes of the product. Thus the more efficient the classification the lower is K, which should be as low as possible for the purpose in view. Since the surface area produced is proportional to the kWh used, the surface produced per kWh and the classification quotient would enable the ore dresser to determine the size of the equipment required, since it is possible from these data to calculate the maximum size of every product for different kinds of comminution. For paper by J. Murkes, *see under* General Papers, Crushing and Grinding Practice.

101. **Apparatus for the Measurement of Time of Impact.** KIRBY, P. L. *Brit. J. appl. Phys.*, 1956, 7 (6), 227–8. The time of impact of a freely falling 8 mm steel sphere on a solid "Pyrex" glass slab is measured electrically without direct connection to the sphere and is found to be 18 microseconds at room temperature and within 10% of this value at 700°C. Above this range of temperature the absorption of fractional impact energy increases considerably, and rebound is zero at 1000°C. The ball passes through an insulated ring close to the glass surface and connections to the ring and crucible enable an oscilloscope trace to show the time of impact. The rebound is measured on a vertical scale.

102. **The Significance of Compacted Materials (Concrete, Bricks) for Research on Grinding Processes.** KOHLSCHUTTER, H. W. *Verfahrenstechnik*, 1937, (1), 5–6. Since so many industrial materials requiring crushing consist of particles artificially chemically and mechanically bound, the suitability of such materials as cement mortar and concrete for crushing investigations is discussed. *See* investigations by F. Hoenig.

103. **Deformation of Solids.** KOSTER, J. *Rep. Invest. U.S. Bur. Min.*, No. 3223, 1934, pp. 15–18. Considers breakage mathematically. Shows that energy required in breaking (metals) depends on the rate of loading and that the faster the loading, the smaller the energy required.

104. **Grinding Problems in the Cement Industry.** KUHL, H. *TonindustrZtg*, 1949, 73, 29, 63. *See under* Cement.

105. **The Mutual Grinding of Brittle Solids.** KUZNETSOV, V. D. *J. tech. Phys. Moscow*

(*Zh. tekh. Fiz.*), 1952, **22** (9), 1409–28. This is a mathematical investigation concerning the structure of solids and energy of grinding. Data are presented which attempt to correlate breaking energy with chemical formulae or crystal structure. 13 refs.

106. **The Surface Energy of Solids.** KUZNETSOV, V. D. Gosudarstvennoe Izdatelstvo Tekhniko-Teoreticheskoi Literatury, Moscow, 1954, 213 pp. English translation from the Russian, 1957, H.M. Stationery Office, 8*s*. 6*d*. net. The aim of the book is to link several phenomena, which take place during the failure of brittle materials, with the aid of a single property—surface energy, so that with the knowledge of the one phenomenon it may become possible to predict the others. A further aim is to describe existing methods of determining surface energy of solids and to discuss a number of unsolved problems in this field. 104 figs, 56 tables. 121 refs; includes 34 to the author's previous publications, 20 to those of Rehbinder, and 9 to publications in English. *See also under* Abrasive Grinding and Grinding Aids and Additives.

107. **On the Results of Tests conducted on Crushers.** LAZAR, J. *Epitponyag* (*Building materials*), 1954, **6** (2), 64–76; *Hungarian Technical Abstracts*, 1954, **6** (4), 128. Tests proved that the size distribution of crushed product conforms with ordinary (Gauss) distribution curve. The figure is so completely uniform that the entire curve is determined by a knowledge of a single point, e.g. maximum grain size of pile. The power requirements for various materials are determined. If material is crushed to various grades by changing crusher setting, the power requirements may be graphically determined by Rittinger's law from the size distribution curve.

108. **Physics of the Crushing Process and Mechanics of Jaw Crushers.** LEVENSON, L. B. *Mech. Constr., Moscow* (*Mekhan. Stroit.*), 1954, **11** (1), 27–31. A critical review is presented and the recent hypothesis of T. I. Mukha is discussed.

109. **Some Theoretical Calculations of the Physical Properties of Certain Crystals.** LENNARD-JONES, J. E. and TAYLOR, P. A. *Proc. roy. Soc. A*, 1925, **109**, 476–508. The values of compressibility, elasticity, and other constants of certain crystals of rock salt type are calculated and compared when possible with experiments.

110. **Grinding Resistance of Various Ores.** LENNOX, L. W. *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1919, **61**, 237–49. Figures work on 'mesh-tons' according to the Rittinger law. The −200 mesh is estimated by assuming the material in feed below 200 mesh has the same 'mesh-tons' as the same percentage of finest material in the product.

111. **Fundamentals of Grinding.** MCLAREN, D. C. *Canad. Min. J.*, 1943, **64**, 705–11; 1944, **65**, 153; *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1944, **8** (5), 151. A discussion of the theory and practice of modern grinding. An accurate method of distinguishing the disintegration required is to define it as to: (1) mesh size, (2) unlocking of particles, (3) new surface produced and (4) size modulus. Factors affecting the disintegration are classified, and each is briefly discussed.

112. **Theory of Metallic Crystal Aggregates.** MAIER, C. G. *Trans. Amer. Inst. min.* (*metall.*) *Engrs* (Metals Division), 1936, **122**, 121–75. The author discusses the energy relations of crystal aggregates and the possibility of determining the energy stored in crystals, with reference to calcite. Virtually no data are available on the time–load–deformation relations of rocks and minerals. Extensive work has been done, however, on metals and the author's work indicates that even when fracture does not occur, the Rittinger law applies over a considerable range of deformation; that is, the internal surface as measured by coercive force, is proportional to the energy used in deforming the metal, as indicated by its density. Apparently, therefore, the energetics of metal deformation and mineral crushing are similar except that in metal deformation the surface formed is not a fracture surface but an internal surface (glide planes, grain boundaries).

113. **Researches on the Theory of Fine Grinding. I. Laws Governing the Connection**

between the Number of Particles and their Diameter in Grinding Crushed Sand. MARTIN, G., BLYTH, C. E. and TONGUE, H. *Trans. ceram. Soc.*, 1924, 23, 61–118. Statistical diameter, mean diameter and frequency curves are defined. The size distribution represented by the frequency curve dN/dx is equal to ae^{-bx}. A concept is given to the breaking down of particles in equal ratios, i.e. each grade is a scale reproduction of the preceding grade. An air elutriator is described for the preparation of graded samples and data for tube mill experiments are given. The influence of the magnifying power of the microscope on the observed frequency of the finest particles is discussed.

114. **Chemistry of Fine Grinding.** MARTIN, G. *Industr. Chem. Mfr.*, 1926, 2, 409. Abstract of paper read before the British Association at Oxford, Aug. 1926. Fine powders were found to behave in many respects like fluids. Experimental work on sand showed: (1) Surface produced is accurately proportional to the work done, this being due to the constant nature of molecular attraction. Substances difficult to volatilize are also difficult to grind. From this and recent determinations of molecular dimensions, the absolute efficiency of a tube mill may be calculated at about 1/15 of 1%. (2) Number of particles increased with decreasing diameter. (3) The average shape remains the same, large or small. (4) In ground sand, the distribution of particle sizes follows the law of probability.

115. **Theory of Fine Grinding. II. Method for Determining Accurately the Surface of Crushed Sand Particles.** MARTIN, G., BOWES, E. A. and CRISTELOW, J. W. *Trans. ceram. Soc.*, 1926, 25, 51–6; *Brit. Abstr.*, *B*, 1926, 903. The surface is determined by loss in weight of crushed sand for one hour in hydrofluoric acid as compared with similar treatment of a measurable surface of quartz. (This work, together with the results of the work of Gross, Zimmerley and Swainson in 1925 on surface measurements, would seem to be a final confirmation of the Rittinger Law.)

116. **Theory of Fine Grinding. III. The Relation between the Work Expended and the Surface Produced in Grinding Sand.** MARTIN, G., BOWES, E. A. and TURNER, F. B. *Trans. ceram. Soc.*, 1926, 25, 63–78; *Brit. Abstr.*, *B*, 1926, 903. This is determined by grinding a given weight in a ball mill for varying periods, measuring the power consumption electrically, and the surface by the hydrofluoric acid method (in II). Results show that surface increase is proportional to work done. The author draws a parallel between the surface increase of a solid and the surface tension of a liquid. The work done per square foot of surface increase varied in a number of experiments from 59·7 to 62·6 foot pounds for 1-in. balls and 45 foot pounds for ¾-in. balls. The cushioning effect of dust in extremely fine grinding is avoided by an air stream. The grinding efficiency was therefore 1/16 of 1%. The dead load was found by filling the mill with concrete blocks. The ratio of power empty to power loaded was 0·24 at 43 rev/min and 0·35 at 54 rev/min. The surface energy of quartz was calculated from the latent heat of evaporation and molecular size.

117. **Theory of Fine Grinding. IV. Air Analysis of Large Quantities of Crushed Sand.** MARTIN, G. and WATSON, W. *Trans. ceram. Soc.*, 1926, 25, 226–9; *Brit. Abstr.*, *B*, 1927, 543. Apparatus for elutriating large quantities of crushed sand is described. The compound interest law connecting size and number was confirmed, log W/x^3 plotted against x giving a straight line. W is the weight of the grade and x the average arithmetical diameter of particles in a grade.

118. **Theory of Fine Grinding. V. Existence and Preparation of Statistically Homogeneous Grades of Crushed Sand.** MARTIN, G., BOWES, E. A. and COLEMAN, E. H. *Trans. ceram. Soc.*, 1926, 25, 240–52; *Brit. Abstr.*, *B*, 1927, 543. By repeated elutriation, crushed sand can be separated into homogeneous grades, in which the average arithmetical diameter of the particles cannot be altered by further fractional elutriation. The homogeneous grades can be considered as units for building up complex mixtures.

119. **Researches into the Theory of Fine Grinding. VI. The Diameters of Irregularly Shaped Crushed Sand Particles Lifted by Air Currents of Different Speeds and Tempera-**

tures. Martin, G. *Trans. ceram. Soc.*, 1927, **26**, 21–33. Stoke's, Newton's and intermediate laws of particle motion are discussed. Results are expressed in the form of a table relating particle size and air velocity.

120. **Researches on the Theory of Fine Grinding. VII. The Efficiency of Grinding Machines and Grinding Media with Special Reference to Ball and Tube Mills.** Martin, G., Turner, F. B. and Linstead, F. *Trans. ceram. Soc.*, 1927, **26**, 34–44. Efficiency of grinding is calculated from determinations of surface of ground quartz, and power consumption for constant sieving analysis is determined. The ball load should be 30–40% of the mill volume, and mill speed, 200/diameter of the mill in inches.

121. **Researches on the Theory of Fine Grinding. VIII. Variation of Specific Gravity of Quartz Sands on Prolonged Grinding.** Martin, G., Watson, W. and Bowes, E. A. *Trans. ceram. Soc.*, 1927, **26**, 45–56. The amorphous layer stated to cover the surface of ground crystalline substances was investigated with a view to showing that such a layer did not affect the rate of solution (in hydrofluoric acid) in surface determinations. Results showed a slight increase of specific gravity during early stages (25–50 minutes) followed by a gradual decrease on prolonged grinding (3½ hours), thus indicating the presence of amorphous silica.

122. **Researches on the Theory of Fine Grinding. IX. Connection between the Statistical Diameter and the Statistical Volume of Irregularly Shaped Particles of Crushed Sand.** Martin, G. and Bowes, E. A. *Trans. ceram. Soc.*, 1927–8, **27**, 247–58. Experimental evidence is presented to show that, with crushed sand of irregularly-shaped particles, a statistical volume constant is given by V/d^3, d being the statistical diameter of the particles, and V the corresponding statistical volume. The mean value for this constant, obtained with five samples of carefully graded, air-elutriated sand, was 0·277. The value was sensibly the same for particles varying in size from 116 520 to 2188 particles per gram. Hence, the average shape of sand particles is the same, whether they be large or small.

123. **The Theory of Fine Grinding. X. The Connection between the Statistical Diameter of Crushed-sand Particles and Their Statistical Surface.** Martin, G. *Trans. ceram. Soc.*, 1928, **27**, 259–84. Makes microscopic measurement on air-elutriated products to determine size, which ranged from 0·0333 to 0·8325 mm. Relation between surface and diameter was found to range from 2·00 to 2·49; the largest value was for the coarse material.

124. **The Theory of Fine Grinding. XI. Calculations Relating to Diameters, Surfaces, and Weights of Homogeneous Grades of Crushed Quartz Sand.** Martin, G. *Trans. ceram. Soc.*, 1928, **27**, 285–89. Gives data on 20 grades of quartz, with 31 000 000 to 1240 particles per g. Discusses methods of calculation for volumes, surface, and weights.

125. **Some Recent Researches in the Science of Fine Grinding done by the British Portland Cement Research Association between 1923 and 1925.** Martin, G. *I.R.I. Trans.*, 1926, **2**, 125–32; *J. Soc. chem. Ind. Lond.*, 1926, **45**, 160–3.T. Mathematical relations concerning powder surface and work done in grinding; heat of volatilization and work done, rate of increase of particles of decreasing diameter, average shape and distribution, are supported by experimental results. Summarizes results in four laws: the surface produced is proportional to the input of work. The number of particles increase with decreasing diameter according to the law of compound interest. The average shape of particles is unaffected by crushing. Any grade of crushed sand is composed of homogeneous grades in which the distribution of the number of the particles with their diameters cannot be altered no matter how often the sand is regraded. Tables of experimental results in support. Cf. Meldau.

126. **Grinding in Ball and Tube Mills.** Martin, G. *Trans. Instn chem. Engrs, Lond.*, 1926, **4**, 42–55. Influence of a current of air on the efficiency. The method of measuring surface of quartz is described (the hydrofluoric acid method), the method of measuring

the electrical energy used by the tube mill and the experimental technique are described. The work required was proportional to the new surface produced up to the fivefold increase carried out. The effect of dust in cushioning the blow is small in the tube mill. Grinding in a current of air did not appreciably save power. A method of determining surface accurately has been devised.

127. **The Laws of Fine Grinding.** MARTIN, G. *Crush. & Grind.*, 1931, **1**, 5–7. Eight laws of fine grinding have been deduced. Their application in practice is explained. Criticism by J. S. Morgan, ibid. p. 43.

128. **The Dependence of Particle Shape on the Method of Grinding.** MELDAU, R. *Verfahrenstechnik*, 1936, (2), 1–6. It is shown with the aid of photographs how the shape of very fine particles of various materials is dependent on the method of grinding, contrary to former opinions. The applicability of this variation in form to particular purposes is pointed out. Cf. Martin.

129. **Observations and Investigations on Industrial Grinding Processes.** MITTAG, C. *Verfahrenstechnik*, 1937, (1), 7–10. In all investigations into grinding operations, a proper understanding of fundamentals is of great importance. Closer basic investigation is necessary, but improvement of equipment and operation will not wait for this. The lack of a comprehensive attack on the fundamentals and technique of grinding is regretted. Examples of advances on empirical lines are given, e.g. roll mills, tube mills. The heat loss in fine grinding is discussed.

130. **Specific Resistance to Grinding.** MITTAG, C. 1925, Verein Deutsche Ingenieur Verlag, Berlin. The differential coefficient of the curve a (energy) to $f(D)$ (fineness), namely da/dD, defines the specific resistance to grinding at the fineness considered and the mean specific resistance from the feed size to the size considered. Experiments showed that the curve of energy a against $f(D)$ could be considered as the summation of the theoretical straight line law and part of a rectangular hyperbola, from which it is possible to derive an equation for $f(D)$, and by differentiation for the specific resistance to grinding S, and the mean specific resistance Sm, in terms of fineness D. Fineness is based on sieving analysis, and the value of S increases rapidly beyond the range of 70% through the particular sieve considered.

131. **Power Requirements in Crushing Machinery.** MITTAG, C. *Arch. tech. Messen*, 6 Aug. 1948, **5**, 8215–6. The consumption of energy in grinding and its distribution are discussed. Up to 50% of the total energy input appears as heat in certain instances. Data are given for various crushers.

132. **Laws of Fine Grinding.** MORGAN, J. S. *Crush. & Grind.*, 1931, **1**, 43. A criticism of Martin's paper of the above title, Ibid., 1931, **1**, 5–7. (1) He doubts Rittinger's law. More power is sometimes used with the mill empty. (2) Deductions from vaporization calculations for energy must be suspect, e.g. an organic material such as rubber should be easy to grind. Also what about heat development when precipitates are formed. There is no substantial heat development. Rittinger's law does not explain this. (3) Materials are rarely homogeneous, even among crystals.

133. **Fundamental Studies in Impact Crushing.** NAKAGAWA, Y., MATSUI, K. and OKUDA, S. *Chemical Engineering (Japan)*, 1954, **18** (4), 146–53. Relation between Energy and Residue in the Crushing of Solids. *Chem. Abstr.*, 1954, **48** (12), 6750. An abstract appears in *Mech. Engng, Lexington, Ky.*, Dec. 1954, **1** (1), 119.

134. **Some Grinding Tests with Spheres and Other Shapes.** NORRIS, G. C. *Bull. Instn Min. Metall., Lond.*, Feb. 1954, **63**, 197–210.

135. **Notes on the Power Used in Crushing Ore, with Special Reference to Rolls and their Behaviour.** OWENS, J. S. *Trans. Instn Min. Metall., Lond.*, 1933, **42**, 407; 1935, **44**, 421. After a discussion of the derivation and validity of Kick and Rittinger hypo-

theses, the author develops an equation for the work done in roll crushing: Work $= C_3(D/S - S/D)$, where D = diameter of particles and S is the roll setting. [P]

136. **The Fundamentals and Laws of Comminution with Special Reference to Metals.** PADSZUS, E. *Arch. Metallk.*, 1947, **1**, 318; 1948, **2**, 576; *Metall. Abstr.*, 1948, **15**, 576. The laws of comminution and the design of grinding mills are reviewed. Theoretically only 0·001 kWh of energy are required to reduce 1 kg of iron to a particle size of 1 micron.

137. **Fundamental Aspects of Grinding.** PIRET, E. L. *Chem. Engng Progr.*, 1953, **49** (2), 56–62. Discusses the methods of measuring surface area and their significance, then the energy requirements as required by Bond and Wang and Bond's later formulae (1952). Experimental results are illustrated graphically using Bond and Wangs' formula (1950). Discusses reaction kinetics, nucleation theory and rate processes, and the lines upon which research might usefully proceed. Bond and Wangs' chart is reproduced (*Trans. Amer. Inst. min. (metall.) Engrs*, 1950, **187**, 871). The author further discusses the heat losses as found in ball mill experiments to be from 75 to 94% of the energy input. Surface production is found with quartz to be directly proportional to work input, but with materials of a plastic nature the curve deflects towards the energy axis. With homogeneous, brittle materials there is no significant temperature effect (−58°–400°C). Possibilities of a 'rate theory' are discussed. Resistance to fracture of brittle materials is a function of time. Plastic flow for steel may be initiated in from 0·001 to 10 seconds and for nylon fibre 1–1000 seconds depending on the forces applied. The curve forms are similar for these materials. Temperature is an important factor in crushing over certain ranges for certain materials. This concerns embrittlement. Rate of loading is a factor. A drop weight machine requires three times the energy of a slow compression machine for equal surface development. Also the slow compression of a bed of quartz particles for the same energy input produces more surface than if impact is used. The times of impact may be microseconds and for compression from a second to minutes. There is also an interval before fracture. There is little quantitative work on the time factor in crushing. Related fields are: Rupture of heat resisting alloys, e.g. time to rupture at constant t and load = log. stress. With glass, porcelain, plastics, chemical agents in fluids or the air can act catalytically and *decrease* the activation energy of fracture. This has a bearing on the rate problem. New approaches are necessary, e.g. a rate approach. The problem is therefore one of chemical engineering. With regard to nucleation theory (W. George, Symposium on Nucleation, *Industr. Engng Chem.* (*Industr.*), 1952, **44**) Piret says that the analogy of the thought of a rate-controlling step and a corresponding activation energy is found in modern nucleation theory and in the theory of rate processes, and it is proposed that this attack be made on crushing processes. While successive steps in fracture appear to be complex, the controlling process may be essentially quite simple. 18 refs.

138. **Crushing and Grinding Efficiency.** PRENTICE, T. K. *Bull. Instn Min. Metall., Lond.*, 447, March 1946; *S. Afr. Min. (Engng) J.*, 1946, **57**, 427. In this paper evidence is submitted which supports the increasingly growing belief that the energy absorbed in crushing and grinding is directly proportional to the new surface area produced in the material being comminuted. It will also be indicated that the efficiency of crushing and grinding machines ranges from about 40 to 20%, depending upon the type of machine and the nature of the work it is called upon to perform. It will be shown that, of the total power input to a machine, only from 55 to 90% is available to achieve comminution, the balance being dissipated in the prime mover and in transmission and friction losses, etc. It will also be shown that over 80% of the energy available to achieve comminution appears in the form of heat, which is dissipated in the surrounding bodies. The fact that deformation of rock under compression or tension up to the point of fracture is approximately proportional to the volume of the rock does not easily conform with the finding that the energy absorbed in achieving comminution is directly proportional to new surface produced; and, for this reason, all the data in

connexion with the experimental tests are submitted in some detail. The author may have erred in some of his deductions, but it is hoped that the presentation of the detailed data might assist in the elucidation of the complex theoretical and practical problems associated with crushing and grinding. Large scale experiments indicate that on Rittinger's law, efficiencies are 32·8% for gyratory crushers, 34·7% for stamps and 23·4% for cylindrical mills.

139. **Determination of Energy Requirements: Reduction of Minerals.** REYTT, Karl von. *Öst. Z. Berg-u-Hüttenw.*, 1888, **36**, 229–31, 246–9, 268–70, 283; *Z. Ver. dtsch., Ing.*, 1888, **32**, 229. From experiments with a number of different crushing machines he concludes that the ratio of the net work input to the surface produced is fairly constant for the coarser sizes, but for smaller sizes the amount of surface produced increases more rapidly than the amount of work required. The difficulties in estimating the numbers of particles and surface area of the fraction 0·1 mm to 0 were emphasized, even by microscopic examination. The mean size 0·1 and 0·0 was discussed for calculation of surface. The older method of calculating surface area from the quantity of water adhering to wetted particles was abandoned as inaccurate, and direct calculation was adopted.

140. **Lehrbuch der Aufbereitungskunde** (Text book of Mineral Dressing). RITTINGER, RITTER, P. VON, 1867, Ernst & Korn, Berlin; p. 19. From a theoretical analysis of the subdivision of a cube, Rittinger deduced that the work required in crushing is nearly in direct proportion to the reduction in diameter, or to the reciprocal of the diameters, and is directly proportional to the surface produced. $E = C^1(S_2 - S_1)$.

141. **A Study of Grinding Efficiency and Its Relation to Flotation Practice.** ROSE, E. H. *Engng Min. J.*, 28 Aug. 1926, 331–8. The average diameter of −200 mesh as assigned may be far from the truth, and grinding to −200 mesh represents an indeterminate amount of unavoidably wasted energy and the efficiency figures obtained by Rittinger law are not translatable into operating terms. Proposes new method based on dependable information: sieve sizing, tonnage treated, and power input. The information lacking is theoretical energy required for crushing, comparative crushing resistances, and differentiation between useful and useless energy. States that useless grinding should not be credited to grinding mills. The proposed method is based on the nearness to completion which is taken as 200 mesh; all passing 200 mesh represents 100%.

142. **Laws of Similarity in Comminution Processes.** ROSE, H. E. Verein Deutsche Ingenieur, Staubtechnik Tagung. (Air purification and Dust Technique.) Dec. 1955, 6–7.

143. **Theory of Crushing and Grinding.** ROSIN, P. Theoretical papers are found by Rosin and collaborators under Coal and under Size Distribution.

144. **Grinding and Grinding Machinery.** ROSIN, P., and RAMMLER, E. *Chem. Fabr.*, 1933, **6**, 395–9, 403–5; *Chem. Abstr.*, 1933, **27**, 5582. For most powders which have undergone fine grinding the relation between R, the residue left on a sieve, and the grain size (x) is of the type $R = 100e^{-bx^n}$, b and n being constants. This enables the curve between R and x (x is in mu) to be obtained from two determined points and the sp. surface of the powder to be calculated. This is not the case with coarse-grinding. Relations of capital and power costs to the fineness of grinding in various cases are shown by curves. Curves showing the relationship between speed of revolution and fineness of product of centrifugal mills and roller mills are also given. Drum mills have an optimum degree of filling for which throughput is a max. Ball mills have a crit. speed of rotation at which the balls revolve evenly with the walls. The optimum speed is some fraction of this, depending on the filling; in some cases there are two optimum speeds. Water content of material to be dried is often important; coal is best dried while being ground. It is very uneconomical in power to run a mill at reduced through-

put, and the power consumption is also affected by the efficiency of the screens or other devices for removing fines.

145. **Calorimeter Method for Studying Grinding in a Tumbling Medium.** SCHELLINGER, A. K. *Min. Engng, N.Y.*, 1951, 3, 518–22; *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1951, **15** (8), 284. The efficiency of a revolving grinding calorimeter is described in which the brittle material is ground by tumbling cast iron shot in a brass grinding chamber enclosed in a water jacket. Method of calibrating and using the calorimeter is described together with a few preliminary results. The thermodynamic efficiency of this type of grinding has been ascertained at least as to order of magnitude. (Paint Research Association, Nov. 1951.) With runs on $-100+200$ quartz, the author found the thermal efficiency to be a function of mineral quality, pulp density and the like. A range of 10–19% thermal efficiency was obtained and peak efficiencies in wet and dry grinding were similar. Efficiency dropped with dilution. The results were comparable with earlier work on the subject and similar to his own data on commercial mills. The construction of the mill calorimeter is described and illustrated. The optimum value of 19% agrees qualitatively with the values found by earlier investigators and is about 50% of the value found by Gross and Zimmerley for commercial ore grinding mills. *Rep. Invest. U.S. Bur. Min., No.* 2948, 1929, Efficiency of Grinding Mills, and *Rep. Invest. U.S. Bur. Min., No.* 3056, 1931, A Device for Determining Work Input to a Laboratory Mill. 7 refs. [P]

146. **Approximation of Energy Efficiencies of Commercial Ball Mills by the Energy Balance Method.** SCHELLINGER, A. K., and LALKALKA, F. D. *Min. Engng, N.Y.*, 1951, 3, 523–4. The controversial nature of energy efficiency figures led to an approximation of such efficiencies by an energy balance of kinetic, heat and surface energy for a mill grinding cement raw materials. All considerations gave the energy efficiency approximation formula:

$$\% \text{ Energy Efficiency} = \left(1 - \frac{\text{Thermal energy output}}{\text{Kinetic energy input}}\right) \times 100$$

Results of calculations made by and with the methods and data discussed are tabulated. Thermodynamic efficiencies obtained by these approximations seem to confirm the results of other workers. Kinetic energy input figures were used, that is after correcting for mill friction, etc.

147. **Energy/New Surface Relationship in the Crushing of Solids. VI. Effect of Temperature.** SCHULZ, N. F. *University of Minnesota, Publication*, No. 3421, 1951; *Dissertation Abstracts, Ann Arbor, Michigan*, 1952, **12** (6), 824. Experimental results showed that temperatures between 25° and 400°C had very little effect on the crushing of quartz, taconite, magnetite. Other conclusions: (1) a practical correlation between surface area and size analysis, whereby surface area could be estimated from the proportion passing a specified sieve size; (2) surface area increased 5% by attrition during half hour's sieving; (3) 20–50% of gross energy is wasted in scoring the faces of the drop weight crusher; (4) the energy of crushing is very nearly proportional to the surface area produced, thus confirming Rittinger's law; (5) a new method of calculating the net energy input to crushing in a drop weight crusher was devised.

148. **Particle Size Studies.** SCHWEYER, H. E. *Industr. Engng Chem.* (*Industr.*), 1942, 34, 1060–6. A study of the progress of reduction and surface development in the sub-sieve range. *See under* Superfine Grinding.

149. **Laws of Grinding in Cylindrical Mills.** SEGUITI, T. *Rev. Industr. min.*, 1952, 33 (7), 537–46. *See* No. 1614.

150. **The Physical and Technical Laws of Work in Size Reduction.** SMEKAL, A. *Verfahrenstechnik*, 1937 (5), 159–68. A distinction must be made between these, and their relation to the Kick and Rittinger laws is discussed. The "technical working law for fine grinding" has nothing to do with the Rittinger law, but relates to the loss of energy in

grinding machines. An attempt is made to define the significance of the relation between the loss of energy and the increase of surface area. 2 refs.

151. **The Physics of Crushing.** SMEKAL, A. *Chem. Apparatur*, 1937, **24** (1), 1–3. It is shown that the theoretical strengths of homogeneous materials are from 100 to 1000 times as great as the actual strengths. This is due to non-homogeneous points in the material, and fracture spreads from such points. There is thus a zone of coarse disintegration which begins separately in non-homogeneous points of maximum stress; a zone of fine disintegration when a large number of homogeneous points are present, in which case the work of crushing approaches an average value; and a zone of very fine disintegration where irregularities again occur and the energy of crushing increases.

152. **The Physics of Crushing.** SMEKAL, A. *Verfahrenstechnik*, 1936 (2), 35. A short review of the objectives and problems of crushing and grinding technology, with reference to the results of the working committee on size reduction, section of the process technology group of V.D.I., whose results have served to clarify the physical and technical bases of this subject. *See also* Smekal, *Chem. Apparatur*, 1937, **24** (1).

153. **Laws of Failure of Solid Bodies Due to Stress.** SUNATUNI, C. *Tohoku University Tech. Rep.*, 1922, **3** (1), 1–56. The inadequacy of previous laws of failure under tensile and shear stress is shown, and new laws are put forward as a result of geometrical and mathematical analysis. The work is intended to throw light on the strength of structures.

154. **A Study of the Particle Size Distribution in a Concentra Type Mill.** TANAKA, T., and SAITO, N. *J. Jap. ceram. Ass.*, 1952, **60**, 99. From a study of grinding rates of cement clinker in relation to its passage through a 5-compartment Concentra type mill, the most effective conditions of operation are deduced. *See under* Cement.

155. **History of the Strength of Materials.** TIMOSHENKO, S. P. 1953, McGraw Hill Publishing Co. (with a brief account of the history of the theory of elasticity and theory of structures). 439 pp.

156. **Method for Estimating the Efficiency of Pulverizers.** WILSON, R. *Trans. Amer. Inst. min. (metall.) Engrs*, 1938, **129**, 170–84; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 810, 1937, 15 pp. Application chiefly to cement clinker. The apparatus consists of a 2½-in. diameter anvil and plunger, on which a steel ball of 2½-in. diameter is arranged to fall. A prepared sample of 20 or 28 mesh is crushed. Soft metal supports absorb loss of energy in the anvil, which may be up to 85%. Cement clinker was used for the tests and the surface per unit of energy used was compared with factory cement output in surface barrels per kWh (total energy). Efficiencies taking the impact test as standard ranged from 19 to 43%. He regards much of the grinding in a conventional mill as being done by impact shatter. The basis is that of surface production, for which very careful measurements were made, including that of the turbidimeter for the finest particles. Results show that the resistance to grinding on a surface basis, increases with fineness of product.

157. **Crushing and Grinding.** WORK, L. T. *Industr. Engng Chem. (Industr.)*, 1950, **42**, 26. Results have been reported on solids such as quartz, glass, etc., in which crushing is accomplished by the dropping ball method and surface areas are measured by permeability. A paper has been presented on the Aerofall mill. This mill seems adaptable for large-size material with reduction to very fine sizes or to intermediate sizes; for the fine sizes, air sweeping and size classification are employed.

158. **On the Theory of Crushing Minerals.** ZVAGIN, B. M., ROSENBAUM, P. B., TODEC, O. M. and UROVSKI, A. Z. *Bull. Acad. Sci. U.R.S.S., tech. sci. (Izv. Akad. Nauk, S.S.S.R., O.T.N.)*, 1950 (7), 1062–70. The authors are concerned largely with the establishment of a theory connecting the amount of crushing with the degree of exposure of minerals and the final composition of the mixed particles. Graphical and mathematical analysis.

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159. **Energy—New Surface Relations in the Crushing of Solids.** ADAMS, J. T., *et al. Chem. Engng Progr.*, 149, **45** (8), (11), (12). 3 papers. Nos. 4, 5 and 6.

160. **Handbook of Ore Dressing.** ALLEN, A. W. 1920, McGraw Hill Book Co., New York. 250 pp. The chapter on the theory of crushing pp. 45–53 deals with the Kick and Rittinger theories and Stadler's support of the former. Mill data are tabulated for energy consumption, size distribution and surface development. The data seem to support either hypothesis.

161. **An Investigation on Rock Crushing Made at McGill University.** BELL, J. W. *Trans. Canad. Min. Inst.* (*Inst. Min. Metall.*), 1916, **19**, 151. In 1911 Galloway's results indicated the Rittinger law to be incorrect. McGill, therefore, adopted Kick's law. In 1913 errors discovered in power measurements led to a new series of tests using crushers, rolls, and Huntington mill, which showed in every case a great increase in EU/h.p. as size of feed was increased, while the Rittinger calculations, although erratic, showed constant SU/h.p. irrespective of size of feed. 'Considered as a whole the results are in closer agreement with Rittinger theory when the two objects which conspire to defeat the purpose of the investigation are taken into account. One is the difficulty of measuring the power used in crushing only. The second has to do with the measurement of the surface in the −200 grade.' Abstract of the paper by this author appears in *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1917, **57**, 133.

162. **The Laws of Crushing.** BELL, J. W. *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, (*Milling Methods*), 1943, **153**, 312–22; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1415, 1942. Criticizes Gross's remarks about the hopeless Kick v. Rittinger dispute. Discusses various opinions and then quotes A. F. Taggart (Tests on Hardinge Conical Mill, *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1918, **58**, 126–55) to support his own and Gates' papers to show that Stadtler's hypothesis (Kick) when investigated experimentally is worthless. Suggests research into the surface energy of quartz, to shed further light on the problem. Discussion: J. Dasher, U.S. Bureau of Mines, attacks Bell's work and quotes Bennett on Rittinger and Mahomet's coffin. (Elsewhere Bell's paper is not regarded favourably.)

163. **The Laws of Crushing and Grinding: The State of Research and the Results Obtained.** BLANC, M. E. C. *Rev. Industr. min.*, 1937, **386**, 35–43. It is concluded that Rittinger's law is confirmed by results. The crusher producing least fines absorbs least energy, other things being equal. This is not the overriding feature however, since quality in the product must be the chief consideration. 36 refs.

164. **A New Theory of Comminution.** BOND, F. C., and WANG, J. T. *Min. Engng, N.Y.*, 1951, 3 (11), 983–6. Discussion by H. J. Kamack and R. G. Wuerker. Kamack: The arguments by Bond and Wang presented against the Rittinger theory do not stand critical examination. The 'Strain-energy' theory which they propose instead, is not supported by the empirical data they present and is disproved (for grinding) by an experiment which shows that for sand the energy required for grinding is not necessarily proportional to the reduction ratio. Kamack supports his views by experimental data. Wuerker: the R. theory appears superficially logical, but the real test as to applicability has still not been correlated satisfactorily with operating results. Its general acceptance may have retarded discovery. The 'strain-energy' theory is an attempt to find a way out of empirical darkness. 18 refs.

165. **Recent Advances in Crushing and Grinding.** DEAN, R. S. *Bull. Amer. ceram. Soc.*, 1937, **16**, 9–11. Results of experiments with magnetite shows that Rittinger's law has been verified for this material.

166. **Some Fine Grinding Fundamentals.** FAHRENWALD, A. W. *Trans. Amer. Inst. min.* (*metall.*) *Engrs* (Milling Methods), 1935, **112**, 88–115. Deals briefly with the

views on Kick and Rittinger laws. Analyses in detail all aspects concerning the functioning of the ball mill. Graphic representations of various relations. It would seem that Gaudin, Gross and Zimmerley have shown experimentally and graphically that Kick's hypothesis cannot possibly hold. *Min. & Metall., N.Y.*, Oct. 1929, 447–8. 32 refs.

167. **Kick v. Rittinger. An Experimental Investigation in Rock Crushing, Performed at Purdue University.** Gates, A. O. *Trans. Amer. Inst. min. (metall.) Engrs*, 1915, **52**, 875–909. The two laws are stated. The Kick law is: 'the energy required for producing analogous changes in configuration of geometrically similar bodies of equal technological state varies as the volumes or weights of these bodies.' The author instances the breakage of a ton of 16-in. cubes to 1-in. cubes in the first place and then to $\frac{1}{16}$-in. cubes in the second place. According to Rittinger, the energy ratio should be 16:1 in favour of the second breakage. By Kick's law, the ratio is 1:1. This discrepancy was thought to be worth a practical investigation. The method of tests was by slow compression machine provided with sensitive indicators of distance and pressure. The results were much in favour of Rittinger's law. Former results from stamp mills were also held to favour Rittinger's law. The −200-mesh fraction was ignored in the author's tests. In the discussion on the paper the protagonists of the two theories maintained their positions. Many other physical features of the fracture process observed during the tests are illustrated diagrammatically and graphically, and make the paper very valuable apart from the K. and R. hypotheses.

168. **The So-Called Kick Law Applied to Fine Grinding.** Gaudin, A. M., Gross, J., and Zimmerley, S. R. *Min. & Metall., N.Y.*, 1929, **10**, 447–8; *Brit. Abstr.*, B, 1929, 927. Calculations were made on the basis of impact tests by Gross and Zimmerley (*Trans. Amer. Inst. min. (metall.) Engrs*, 1930, **87**). It is shown theoretically that in grinding fine sizes the efficiency, according to the Kick law, increases enormously when compared to surface energy. Efficiency passes 100% at about 0·1 micron size, and at 0·001 micron size it reaches several thousand per cent. It is concluded that the Kick law cannot possibly hold.

169. **Contribution on the Study of the Fragmentation of Materials.** Gosset, M. L'Equipement Mécanique des Mines, Carrières et Grandes Entreprises, May, 1949, 5–12. A mathematical interpretation of the laws of grinding. The laws of Rittinger, Kick and Stadtler are shown to be contradictory. Their lack of generality is emphasized and the cases where they are individually applicable are defined.

170. **The Laws of Crushing.** Herman, J. *Engng Min. J.*, 1923, **115**, 498–500, Discussion, 789–91. Six years of custom grinding, using a Herman screening ball mill on material varying from insect powder to granite (26 materials are listed) have given the opportunity to test the laws of Kick and Rittinger. The results are more in accord with Rittinger than with Kick, and the agreement increases with increase in efficiency of grinding. Results are presented in curves which show close agreement with the Rittinger law. The discussion by Hardinge dealt with eight general aspects of ball-mill grinding, but contained little that was relevant to Herman's theme.

171. **A Contribution to the Study of Comminution—A Modified Form of Kick's Law.** Holmes, J. A. Paper to the Institution of Chemical Engineers, London, 7 Nov. 1956. The problems encountered in the formulation of a theory of comminution are indicated and a general equation relating energy and particle size is developed based on a suitably modified form of Kick's law. This equation is expressed in the form $W = Wi[1-(1/R)^r](100/P)^r$ where W, Wi and P have the same connotations as in Bond's equations, R is the reduction ratio (linear) and r is the Kick's law deviation exponent. If $r=1$, 0 or $\frac{1}{2}$, the equation corresponds to the theories of Rittinger, Kick and Bond (3rd theory) respectively. The limitations of the above equation are discussed and its application to prediction of power requirements for ball mill grinding in closed circuit is illustrated for a variety of materials. Results are discussed with particular reference to the significance of existing theories. Rittinger's theory fails because it is

related to surface area, which is an unimportant parameter in size reduction. Kick's law fails only because it requires that materials be perfectly annealed and homogeneous. The Third Theory should be regarded only as an extremely useful empirical method of prediction of power requirements for comminution. The basic postulate relating energy and particle size has no real significance, and leads to an oversimplified picture. 13 graphs, 21 refs.

172. **Mechanical Efficiency of Crushing.** KENNEY, H. C. *Min. sci. Pr., San Francisco,* 10 April 1915, 572–5. Gives a theoretical discussion. Kick's law implies deformation only, not rupture, but also applies after rupture. Discusses both laws mathematically and graphically and concludes that both laws may hold. He states that Rittinger's law appears the most reasonable but needs direct experimental evidence of proof, and that argument without such proof is of no value.

173. **The Theoretical Aspect of Crushing and Grinding.** MICHELL, F. B. *Mine & Quarry Engng,* 1939, 4, 359. A review is presented of Rittinger's and Kick's theories in the light of recent experimental evidence and their bearing on comparative efficiency calculations in practice. Rittinger's theory states that the work done is proportional to the reduction in diameter; while according to Kick, for any unit weight of ore particles, the energy required to produce any desired reduction in volume of all the particles in the mass is constant, no matter what the original size of the particles.

174. **Kick v. Rittinger: An Investigation of the Laws Governing Crushing in Ball Mills.** ROLPH, E. A. *Canad. Min. J.,* 1922, **43**, 550–53. Presents both the Rittinger and Kick laws in a form that can be quickly grasped and easily applied. Graphic representation and calculations made according to the two laws show their difference. Although Kick's law might appear the more logical, experimental work has served to show it is not applicable, while that of Rittinger conforms with the results of experiments.

175. **A Survey of Research on Rock Crushing.** SHAW, E. *Rock Prod.,* 20 July 1929, 70–5. Complete survey which explains Rittinger's law, work of von Reytt, Wagoner, and Richards, and Stadtler's contribution that crushing follows the Kick law. Discusses work of Gates, Haultain, Bell, Gaudin, Martin, and Gross and Zimmerley.

176. **The Application of Kick's Law to the Measurement of Energy Consumed in Crushing.** SPEAK, S. J. *Trans. Instn Min. Metall., Lond.,* 1914, **23**, 482. Kick's law stated thus—To break 1 cu. in. of material into 2 pieces requires 10 times more energy than to break a piece $\frac{1}{10}$ cu. in. into 2 pieces. Suggests that tenacity may increase as particles become smaller (cf. the tenacity of spun glass). Cleavage at planes of weakness alters the validity of Kick's law, (cf. Stadtler's paper. *Engng Min. J.,* 1914, **98**, 905.

177. **Grading Analyses and their Application.** STADTLER, H. *Trans. Instn Min. Metall. Lond.,* 1910, **19**, 471, 509; 1911, **20**, 420. Presents reasoning for applying Kick's law to crushing, using ordinal numbers, mechanical value, and relative mechanical efficiency in calculating the work done in crushing. Definitions of these quantities and their application. Recommends a standard sieve series more convenient in using Kick's law.

178. **The Law of Crushing. I and II.** STADTLER, H. *Engng Min. J.,* 1914, **98**, 905–8, 945–8. The author takes the view that crushing energy is proportional to the volume, i.e. he agrees with Kick's law. He compares various crushing laws as used by Caldecott and Pearce, Klug and Taylor, R. W. Chapman, and Stadtler. Really a comparison of Rittinger and Kick laws. Rittinger's law is fallacious as 'force' and 'work done' cannot both be proportional to the area of rupture. The distance through which force operates in doing work is disregarded in the Rittinger law. Gives a theoretical discussion proving the correctness of Kick's law. Discusses the work of Gates, Bell and Taggart. Gives the method for computing crushing efficiencies based on Kick's law,

using ordinal numbers or energy units. Admits that useless work is done. *See also* S. J. Speak.

179. **The Work of Crushing.** TAGGART, A. F. *Trans. Amer. Inst. min. (metall.) Engrs*, 1914, **48**, 153–79. Gives a theoretical discussion of Rittinger and Kick laws. Concludes that Kick's law applies to a *crushing* operation. Discusses the work of Del Mar and of Gates. Includes examples of calculations of efficiencies in crushing, method for calculating the ordinal number, as per Kick's law, and table of constants for Tyler sieves.

180. **Practical Crushing Efficiency.** TAPLIN, T. J. *Min. Mag., Lond.*, 1934, **50**, 18, 87. The mathematical basis of the K. and R. laws limits them to elastic and homogeneous solids. Kick's law considers only the energy to stress the particle to the point of fracture and may be termed Energy of Preparation, E_p. Rittinger's concerns energy of actual fracture E_f. Therefore the two laws are complementary, but either carried to extremes leads to absurdity. The ratio E_f/E_p is shown to be 1/25 000 D for quartz (D = diameter in inches). The ratio is very small therefore for all but the smallest particles. The energy of preparation is liberated after fracture and might possibly be conserved and transferred to other particles in rapid fracture. Theoretical surface energies, assuming a perfect lattice structure, have been much overestimated; the author regards the surface energy of quartz as 34 ergs/sq. cm. rather than as Edser's value of 920. Kick's law is approximately valid for coarse crushing, and for crushing tough ores. Rittinger's law is more appropriate in fine grinding because of increase in the ratio E_f/E_p.

181. **A Text Book of Ore Dressing.** TRUSCOTT, S. J. 1923, Macmillan & Co. Ltd., London. Gives work done in crushing and states that the Rittinger law seems unreasonable as the amount of work represented by the fine material is so large. Assumes the Kick law to be the correct law of crushing, using Stadtler's arguments.

182. **Some of the Mathematical Laws of Crushing.** WARWICK, A. W. *Min. World, Seattle*, 1910, **33**, 173–5. Explains Rittinger law. In ores of various constituents, Kick's law cannot hold. Discusses the effect of water and natural slimes in ores as affecting the results when calculated by the Kick law.

183. **The Status of Testing the Strength of Rocks.** WUERKER, R. G. *Min. Engng, N.Y.*, 1953, **5**; *Trans. Amer. Inst. min. (metall.) Engrs*, 196 (11), 1108–13. The progress made in testing the strength of rocks and minerals, as they are encountered in mining operations, is reviewed. An attempt is made to correlate these physical measurements with abrasive hardness, grindability, and behaviour in comminution on the one hand, and the fracture of rocks in pillars and roof control on the other. Experimental work has proved the applicability of the theory of elasticity and the standard methods of testing materials, to rocks, ores and other materials with which operators have to deal. Knowledge of strength of rocks should be increased by more exact testing and agreement on procedures. The results of investigations are presented graphically. 20 refs. The investigations were on elastic deformation of rocks, stress-strain curves for coal and other brittle materials and on the effect of time of loading. The work was part of a comprehensive programme of investigation on the strength properties of rocks at the Department of Theoretical and Applied Mechanics, Illinois University.

MECHANISM OF FRACTURE

184. **On the Mechanism of Breakage.** ANDREASEN, A. H. M., WESENBERG, B., and JESPERSON, E. G. *Kolloidzschr.*, 1937, **78**, 148–56. The distribution formulae of Martin, Rosin and Rammler, Gauss, Heywood are discussed. Size distribution tables for crushed glass, felspar and earthenware are presented. Three hypotheses for the breakage mechanism are put forward, two of which are present in agreement with Griffith in his *Handbuch der Physik*, Berlin, 1928, p. 455. The three hypotheses for the mechanism are embodied by the author in an idealized diagram, where the finest material is shown to be in the middle of the crushed block. The diagram is confirmed by the disposition

and shape of cracks and crushed product from glass and felspar cubes, crushed in a 5-ton press. According to Griffith the breaking of a brittle amorphous solid by a pure pressure load can be regarded as a fracture break similar to the effect of a tensile stress.

185. **The Plastic Deformation of Fine Particles of Coal and other Materials.** BANGHAM, D. H., and BERKOWITZ, N. *Coal Res.*, Dec. 1945, 139–50. The authors have examined the cold flow of coal particles following Boddy's observation that the particles can be pressed out into sheets on a microscope slide. The property is associated with micellar structure of the coal particles and they consider that shearing takes place at inter-micellar boundaries across which weak (surface) forces are acting. The deformation is facilitated by the presence of adsorbed water vapour. 10 refs. (*Coal Research* is issued by the British Coal Utilisation Research Association.)

186. **A Two-Stage Phenomenon in the Breakage of Coal.** BOND, R. L. *Fuel, Lond.*, April 1954, 33 (2), 249. Under impact, coal is seen to break into a few large pieces in some cases, and in others to give a considerable amount of dust. Drop-hammer experiments on 500-g (approx.) cubes of coal of various grades (about 1 in. side), placed with cleavage planes either normal to or in the line of application of blow, indicated that if the forces applied are sufficiently small, the breakage occurs in two distinct stages: firstly, failure at a few preferred sites, giving a small number of relatively large pieces, and secondly, the production of dust. The sequence was (1) no visible change, (2) cracking in both directions, (3) separation along the cracks into smaller pieces (often only two), (4) retention of shape under further impact until complete shattering occurred with production of fine material. The hammer was tripped to give repeated blows at one second intervals from a 10-cm height.

187. **The Time Delay for the Initiation of Plastic Deformation at Rapidly Applied Constant Stress. (Tensile Loads.)** CLARKE, D. S., and WOOD, O. S. *Proc. Amer. Soc. Test. Mater.*, 1949, **49**, 717–35. 19 refs.

188. **Materials are Quite Dissimilar in Tension and Compression.** COFFIN, L. F. *J. appl. Mech.*, Sept. 1950, **17** (3), 233.

189. **Plastic Deformation of Crystals.** COTTRELL, PROF. A. H. International Series of Monographs on Physics. 1953, Clarendon Press. 228 pp. 25*s*. 0*d*. An appreciation by N. P. Allen in *Nature, Lond.*, 14 May 1955, p. 830.

190. **Dislocations in Metals.** CUFF, F. B., and SCHETKY, L. McD. *Sci. Amer.*, July 1955, **193** (1), 80–7. It is shown how the dislocation theory can account for the strength properties of pure and impure metals, how strength is increased by the blocked build up of dislocations during work hardening, how the inclusion of impurities known as the 'Cottrell Atmosphere' affects yield point, how regrouping of impurities improves hardness in annealing at the optimum regrouping for blocking dislocation movement, and how random dislocations line up during heating and bending to give an ordered arrangement of minimum strain in the lattice and therefore greater strength of the metal.

191. **Discussion on Age Hardening of Aluminium Alloys.** DEAN, R. S. *Trans. Amer. Inst. min. (metall.) Engrs.*, Feb. 1936, **122**, 294. R. S. Dean has been developing the theory of internal surface for some time and develops the concept at some length in this paper. He assumes the presence of glide planes when a material changes shape but is not fractured.

192. **Statistical Aspects of Fracture Problems.** EPSTEIN, B. *J. appl. Phys.*, 1948, **19** (2), 140–7. A survey of the development of statistical theories of the strength of materials and of the dependence of strength on specimen size. The problems posed are equivalent to an important problem in mathematical statistics and the calculations made by mathematical statisticians give a far more complete description of the results to be expected than do the estimates to be found up to now in the technical literature.

193. **A Statistical Theory of Fracture.** FISHER, J. C., and HOLLOMAN, J. H. *Trans. Amer. Inst. min. (metall.) Engrs*, 1947, **171**, 546–61; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 2218, 1947. An attempt, using statistical analysis, to rationalize the size effect in solids, the scatter of fracture stress values, and the dependence of fracture stress upon strain, and to suggest a quantitative relation between the structure and the fracture stress.

194. **The Behaviour of Brittle Materials at Fracture.** FROCHT, M. M. *J. Appl. Mech.*, 1936, **3** (3), A.99–103. The effects of holes, notches, etc., is discussed for the breakage of tensile test specimens of bakelite. Stresses are observed by photoelastic means and calculations made therefrom.

195. **The Phenomena of Rupture and Flow in Solids.** GRIFFITH, A. A. *Phil. Trans. A*, 1921, **221**, 163–98. A theoretical criterion of rupture. Application of theory to a cracked plate. Experimental verification of the theory. Method of finding the surface tension of glass (by extrapolation from values at liquid). Table of values given. The strength of thin fibres. Molecular theory of strength phenomena (molecular orientation and grouping). Extended applications (to metals). 'The theory suggests that the drop in stress at the initiation of yield is due to the surface energy of the intercrystalline boundaries.' Application of theory to liquids (the ring and ball experiment indicates that the molecular grouping in liquids is comparable with that in solids). Experimental work confirms that a thin film of liquid between solid boundaries which it wets, should act as a solid. The author accounted for the behaviour of glass under rupture tests on the supposition that fine cracks were inevitably present, and showed experimentally that freshly drawn glass threads were much stronger than older ones. The hypothetical cracks were in the body of the material.

196. **The Brittle Fracture of Metals.** HALL, E. O. *Journal of the Mechanics and Physics of Solids*, July 1953, **1** (4), 227–33. A study has been made of the theory of the brittle fracture of metals, where plastic deformation arises during the cleavage process. By the use of X-rays, the magnitude of this plastic work has been investigated on single crystal and polycrystal cleavage surfaces. A theoretical study has also been made of the depth of the plastic zone in single crystals with varying crack velocities. X-ray pictures and photographs. 16 refs.

197. **Single Crystals without Dislocations.** HARDY, H. K. *Research, Lond.*, 1955, **8** (2), 57–60. Single dislocation-free crystals in the form of whiskers are found to grow on some metals. These have exceptionally high tensile strength, higher than that by other methods of formation. The effect of dislocations on stress/strain relations is discussed and the dislocations and movement are illustrated diagrammatically. Whiskers of pure iron may have tensile strength of 400 tons/sq. in. The 'paradox' is complete. A conventional single crystal containing dislocations has the lowest resistance to deformation. A perfect (dislocation-free) single crystal or one of suitably chosen exceedingly small dimensions will have the highest possible resistance to deformation. A rock of small crystals is stronger than one of large crystals. Dislocations will pass across crystal boundaries, although crystal boundaries may act as dislocations.

198. **Strength of Plastics and Glass.** HAWARD, R. N. 1949, Cleaver Hume Press, London; Interscience Publications, New York. Generally agreed that glass breaks only under tension. Confirmed by Preston F. W. 1926, Poncelet 1944. Discusses breakage caused by surface cracks. Curves corroborate this—breaking stress v. depth of crack, but this does not agree with Griffith. Jurkov showed that silica fibres baked out and broken *in vacuo* were 3–4 times as strong as untreated fibres. Preston showed that strength varied with large humidity changes. Jurkov showed that H.F. etching improved the strength of glass. Preston, F. W., *J. appl. Phys.*, 1942, **13**, 623, has shown that over a complete range of results over a factor of 10^7 in time, the bending strength of glass varies by a factor of 3, and is not confined to any particular type of test. A

satisfactory theory for a time factor does not yet exist. But Harries, Holland and Turner, *J. Soc. Glass Tech.*, 1940, **24**, 46, put forward the empirical equation: strength varies as $(1/\text{time})^{\frac{1}{y}}$, where y is empirically determined. y has been determined as 11·9 and 12·8. A more thorough theoretical understanding of the process of rupture is needed, particularly as the existence of an unexplained time element introduces doubt into other measurements. The aspect is complicated by views on 'slow deformation' (which may not even exist since viscosity is so high). *Chapter VI.* Impact Strength of Plastics and Glass. Major Theoretical Factors: (1) time, (2) delayed elastic stress; (3) adiabatic straining; (4) weight factor; (5) vibrational stresses; (6) other effects, e.g. grips, notches. Pp. 146–200, 63 refs. Griffith and Thomas found a linear relation between thickness and impact energy of fracture. The several factors which cause differences in energy absorptions under impact and under static conditions form one of the major problems of impact testing. Time factor static/impact can be 10^5. The time factor for fracture effect occurs with glass and must be considered in every theory of impact strength. It can only be neglected for a narrow range of conditions. 63 refs.

199. **Ultra-fine Structure of Coals and Cokes.** Hirst, W. *Mon. Bull. Brit. Coal Util. Res. Ass.*, Nov. 1943, 7 (6), 201–8. Report of two day Conference at the Royal Institution, June 1943.

200. **Commercial Problems of Size Reduction.** Huttig, G. F. *TonindustrZtg*, 1953, 77 (21/23), 365; *Zement-Kalk-Gips*, 1954, 151–9. The behaviour of solid material during the size reduction process depends on its fine structure, i.e. on the crystal lattice and the linkages which exist between the individual crystals. It has been shown that not only are ideal lattices encountered with uniform, empty spaces, but also damaged and defective places and occluded foreign bodies in the lattice, and that in the environment of these places the linkages are weakened. The linkage spectrum is obtained by graphical plotting of the frequencies of the various linkage strengths, by various experimental methods. Electron microscope examinations which allow of the perception and investigation of the details of the structural formation to be obtained down to 50 Å certainly allow no postulations regarding the linkage strengths but do provide information regarding their space arrangement. The oscillatory frequency of the lattice atoms can be obtained from the Raman spectra and this is a function of the linkage strength. By means of small angle X-ray methods, information can be obtained regarding the sizes of the internal specific surfaces and the linear dimensions of the particles obtained. By a fractional loosening of the linkages it is possible to induce merely a separation of the weak linkages. With mechanical and test processes, it is possible to establish divergences between the theoretical and the actual rupturing strength present. The observations on the course of a milling size reduction process can be represented by six milling functions of which each gives a provisional representation of a definite characteristic of the milling. These are: Throughput characteristic, Frequency, Mill flow, Reduction movement, Milling characteristic, Formation characteristic. With continual milling, a region is reached in which the mill no longer reduces, but begins to weld together the smaller grains to larger ones. A milling equilibrium is attained, at which the characteristic of a powder is no longer changed by further milling. See also *Staub*, 15 Sept. 1954, 37, 363–71, Huttig and Sales. Reproduced in English in *Cement, Lime & Grav.*, Feb. 1955, p. 410.

201. **Fracturing and Fracture Dynamics.** Irwin, G. R., and Kies, J. A. *Weld. J. Easton, P.A.* (Research Supplement), Feb. 1952, 95–103S. Fracturing begins at flaws and is accompanied by considerable plastic deformation. The progressive extension of a fracture requires little driving energy, which may, however, be assessed. It is shown that cracks start slowly until the rate of energy flow into the crack from released stress field becomes greater than the work required by new area formation. Then the crack becomes unstable with spontaneous acceleration until, if sufficient energy is available. the velocity approaches that of sound and branching occurs. Photographs showing internal flaws and propagation of cracks. A curve shows how average crack velocity

increases with increasing initial stress. The dependence on shape factor of the rate of release of stored elastic energy is illustrated. 9 refs.

202. **The Physics of Crystals.** JOFFE, A. 1928, McGraw Hill Book Co., New York. 198 pp. Discusses the mechanical behaviour of crystals and the electrical properties of both single crystals and solid dielectrics. The ability of minerals to deform like metals has been shown repeatedly.

203. **A Study of the Influence of Temperature on the Mechanical Strength of Glass.** JONES, Prof. G. O. Thesis for Ph.D., University of Manchester, 1941. The paper includes a long review of the papers of 18 authors from 1859 on the phenomena and theories of the fracture of glass. For abstract *see under* Glass.

204. **The Formation of Microcracks.** KARPENKO, G. V. *C.R. Acad. Sci. U.R.S.S. (Dokl. Akad. Nauk, S.S.S.R.)*, 1950, **74** (1), 95–8. Rehbinder showed that the greater the surface energy of a solid the greater the difficulty for the solid to form new microcracks. Surface active agents, by lowering the surface energy, aid the formation of new microcracks.

205. **Interpretation of Fracture Markings.** KIES, J. A., SULLIVAN, A. M., and IRWIN, G. R. *J. appl. Phys.*, July 1950, **21**, 716–20. Many materials such as coal, plastics, metals, show the propagation of cracks by the joining up of independently initiated fractures. A number of characteristic fracture markings are explained.

206. **The Strength Properties and Frictional Behaviour of Brittle Solids.** KING, R. F., and TABOR, D. *Proc. roy. Soc. A*, 22 April 1954, **223** (1153), 225–38. Under high hydrostatic pressures, brittle fracture is prevented, marked plastic deformation occurs and the plastic yield stress reaches values very much greater than the bulk shear strength of an uncompressed specimen. Experiments were conducted with rock salt, lead sulphide and ice. 20 refs. *See also* Joffe, No. 93.

207. **Structure Study of Fracture Phenomena.** LEEUWERK, J. and SCHWARZL, F. *T.N.O. Nieuws, Delft*, 1955, **10** (9), 367–72. A translation may be consulted at D.S.I.R. Ref. Records Section, 25772. With aid of a series of photographs and diagrams obtained from the fracture surfaces, under tension and bending of rods of glass, steel and polymethyl-methacrylate, the authors show how a fracture begins at a point origin at a weakness due to inhomogeneity; how the fracture fronts from secondary and tertiary point origins produce relief patterns similar to hyperbole or parabole by intersection with the primary front and each other; and how the interference lines, 'Wallner lines', produced by ultrasonic waves, spontaneously and intentionally produced, can serve for calculation of the speed of the fracture front. A brief discussion of the effects of 'Griffith' cracks and the relation between the theoretical and observed strength of glass and steel follows. 20 figs., 5 refs.

208. **Plastic Deformation of Crystals as the Result of Motion and Displacement.** LEIBFRIED, G. *Z. angew. Phys.*, 1954, 251–3.

209. **Study of Moisture-Condensation Patterns on Glass and Crystalline Surfaces.** LEVENGOOD, W. C. *J. Amer. ceram. Soc.*, 1955, **38** (5), 178–81. A method was devised whereby moisture condensation (breath) patterns on glass and crystal surfaces could be examined under the microscope and photographed. The patterns were markedly influenced by the fracture patterns and structure of the underlying surfaces. The technique was applied in a detailed study of minute surface fracture patterns and Griffith flaws. Experiments were made showing the type of fracture patterns produced on glass by various mechanical means. Variations in surface structure produced by polishing, etching and other treatments were also studied by this method. The evaporation of moisture film was prevented by covering at once with a small chamber, about 1·5 mm in height, made from a glass slide supported on teflon walls. The chamber was heated slightly before covering the film. 20 photos, 7 refs.

210. **Random fracture of a Brittle Solid.** Lienau, C. C. *J. Franklin Inst.*, 1936, **221** (4), 485–94; (5), 673–86, 769–80. In this important mathematical treatment, a brittle solid is defined as one whose tenacity is small in comparison with its rigidity. The inner structure is discussed, and it is postulated that there may be both a coarse and fine structure. The formation of a fissure and the velocity of stress propagation is discussed from a theoretical standpoint. The brittleness is defined by $U/3K$, that is the ratio of the ultimate static tension to three times the bulk elastic modulus. A mathematical theory of random fracture is based on these conceptions. The size distribution of the particles resulting from crushing thin brittle rods was found to be in agreement with the theoretical reasoning, but the theoretical efficiency of crushing did not exceed 1·2%.

211. **Dislocations and the Theory of Solids.** Mott, N. F. *Nature, Lond.*, 7 Feb. 1953, **171** (4345), 234–7. The article is based on three special lectures by the author in the Univ. of London in November and December 1952, and outlines the developments in the attempt first made in 1934 to describe plastic flow of solids on the basis of crystal dislocations. About 40 refs.

212. **Physics of the Solid State.** Mott, N. F. *Advanc. Sci., Lond.*, Sept. 1955, **12** (46), 148–56. The paper deals with self-diffusion in metals, the two methods of estimating the frequency of jumps in atoms, the occurrence of 'vacancies' in the lattice, and the formation and significance of 'holes' in the work hardening, strength and fatigue of metals.

213. **The Physics of Powder Systems.** Nassenstein, H. *Chem.-Ing.-Tech.*, 1952, **24** (5), 272–6. The properties of solids in relation to crystal structure and their relations with surface energy and comminution are discussed. The effects of surface imperfections on the strength of solids is described.

214. **Fracture and Strength in Solids.** Orowan, E. *Rep. Progr. Phys.*, 1949, **12**, 185–232. A discussion of the phenomena and causes of fracture of various kinds and with various materials. The fundamental aspects of the laws applicable are considered. Orowan gives an extensive review and attributes the varying results to size effects, p. 198.

215. **The Brittle Fracture of Ferrous Materials.** Patch, N. J. British Iron and Steel Research Association. Alloy Research Committee Report No. M.G./A/107/40, 1940. The dependence on physical, chemical and granular properties is discussed.

216. **Fatigue of Metals. The Relation of Experiment, Theory and Practical Failure.** Phillips, C. E. *Times Science Review*, Summer, 1955. Fracture under a once applied load always exhibits ductility. Fatigue fractures exhibit brittleness at least over part of the surface. Progress demands that the fracturing process be understood. There is a critical value of stress range, below which most ferrous metals, and some others, will not fracture, however many times applied. No material is really homogeneous. Therefore results vary. The extreme difficulty of calculating stresses near faults (holes) is described. Practical technique is difficult because stress is so highly localized. A fatigue crack begins at the surface and works inwards. A single scratch may have a pronounced deleterious effect. Cold rolled screw threads have about double the fatigue strength of machined threads. Cold rolling and heat treatment, nitriding, shot peening, etc., provide better surfaces for withstanding cracking under fatigue tests. So far not one theory has been found which will account for all known facts. 5 figs.

217. **Fracture and Comminution of Brittle Solids.** Poncelet, E. F. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 37; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1684, 1944; *Ceramic Abstr.*, 1944, **23**, 202. Glass squares compressed on edge by steel jaws in poor contact with them developed jagged 'partial-contact' cracks caused by the formation of local tensile stresses. Compressed by steel jaws in perfect contact, they developed smooth 'release cracks' on release of pressure. All these cracks were parallel to the pressure. A Microflash photograph of a disintegrating specimen under sufficient

pressure reveals a network of fractures roughly normal to each other, together with 'release cracks' and a disintegration cloud. The Griffith theory is amended to account for the formation of a first crack. A new theory, based on the theory of thermal agitation and wave propagation, is proposed to account for the progress, velocity, and forking of cracks. The network of fractures is shown to have been caused by reflection at a free boundary of pressure pulses emanating from a first crack. Postulating equal distribution of energy in the pulses emitted on either side, the smaller fragments are shown to continue fracturing preferentially, while some of the coarser fragments remain as residual pieces. As comminution of the smaller fragments proceeds, the solid is reduced to a collection of residual particles of smaller and smaller sizes, accounting for the disintegration cloud.

218. **On the Fine Structure of Clays.** ROBERTSON, R. H. S. (Glasgow). *TonindustrZtg*, 1951, **75**, 2–6. An investigation into the relation between the fine structure of various earths and their physical properties, e.g. plasticity, etc. 20 refs.

219. **Extension of Griffith's Theory of Rupture to Three Dimensions.** SACK, R. A. *Proc. Phys. Soc., Lond.*, 1946, **58**, 729–36. Griffith's theory of rupture of brittle materials is extended to materials containing circular cracks. It is found that (a) the tensile strength of brittle material in one direction is not affected by stresses at right angles to it, (b) the result differs from Griffith by a factor depending on Poisson's ratio of the material, and lying between 1·57 and 1·81 (Griffith, *Phil. Trans.*, 1921, **221**, 180). 9 refs.

220. **Dislocation Theory, Planes of Weakness, Surface imperfections and the strength of materials.** SMEKAL, A. *Handbuch der Physik, und Technical Mechanik*, 1931, **4** (1); **4** (2).

221. **The Properties of Brittle Solids.** SMEKAL, A. *Ergebn. exakt. Naturw.*, 1936, **15**, 107–88. An extensive investigation into the strength of brittle solids and their resistance to breakage. Surface energy, 'molecular strength', and the effects of surface cracks in relation to strain are discussed and illustrated. 145 refs. Surface imperfections lower the strength as calculated from crystal structure from 1/100 to 1/1000 of the calculated values. Theoretical Bases of Fracture Phenomena, pp. 109–37. Solid Properties of Glass, pp. 137–75. Solid Properties of Crystals, pp. 176–84.

222. **Fracture Theory of Brittle Materials.** SMEKAL, A. *Z. Phys.*, 1936, **103**, 495–525. The effects of thermal and non-thermal stress are analysed. Effects of stress on homogeneous and heterogeneous solids analysed. Photographs in illustration. 50 refs.

223. **Theoretical Bases of Size Reduction.** SMEKAL, A. *Verfahrenstechnik*, 1937 (1), 1–4. The breakage theory for compact brittle solids developed by the author provides a numerical criterion for the grindability of simple homogeneous materials. It also embraces all the factors on which the reduction depends. The important points in the theory are discussed. The factors are: the mature and maximum value of the stress imposed, the temperature, and the structure of the specimen. Photographs show the breaking of a glass fibre under tensile stress where a surface crack started a lateral fracture, and secondary fracture surfaces on the main fracture surface.

224. **Fundamentals of Grinding Hard Materials.** SMEKAL, A. *Z. Ver. dtsch. Ing.*, 1937, **81** (46), 1321–6. The progress of fracture in rock salt and glass is illustrated by photographs taken by sodium light. The relation between energy consumption for individual fractures and for collective reduction is discussed, both being less than 1% of the total energy consumption. Many processes intervene between the source of energy and the application to the product, and so efficiency is reduced.

225. **Reduction of Cubic Solids under Pressure.** SMEKAL, A. *Verfahrenstechnik*, 1938 (6), 159–65. It is shown how the nature of the breakage and the size distribution of the product can be predicted. Former results have shown the relationship between size distribution, particle size and surface area. The present investigation shows how

appropriate is the cube for demonstrating the breaking properties of brittle materials. The mechanism of breakage is illustrated diagrammatically (successively smaller particles according to distance from the two pressure surfaces, upper and lower) and photographically. Stress diagram. 32 refs.

226. **Dislocation Theories of Strength and Plasticity.** STEPANOV, A. V. *Research, Lond.*, 1956, **9** (6), 227–36, Translation by R. Hardbottle from *Bull. Acad. Sci. U.R.S.S.* (*Izv. Akad. Nauk S.S.S.R.*), 1950 (7), 1062–70. The fundamental principles underlying existing dislocation theories are discussed and criticized. Efforts hitherto to explain the origin of dislocations of regular crystals have not been successful. The author proposes an alternative approach to the study of the strength and plasticity of crystals, on the basis of which he surveys possible types of local deformation arising in the centre of dislocations of an anisotropic body and some properties of local deformations. 13 refs.

227. **The Formation of Cracks in Plastic Flow. II.** STROH, A. N. *Proc. roy. Soc. A*, 22 Nov. 1955, **232** (1191), 548–60. The detailed mechanism by which a piled-up group of dislocations generates a crack is considered: it is suggested that a crack arises from short range non-Hookian interactions of dislocations at the head of the pile up, and a model is developed. It is shown that a crack can be initiated by a smaller number of dislocations in each of several slip planes. This may be important in ductile materials.

228. **Attempts to Establish a Mathematical Theory of Brittle Fracture.** SVENSSEN, S. *Tidskrift for Teknisk Vetenskapelig Forskning*, Ingeniorsvetenskapsakademiens, 1955, **26** (7), 326–7. Appendix to a lecture held before the Royal Swedish Welding Commission, 5 Dec. 1955, on 'A Survey of the Brittle Fracture Problem with reference to Future Research'. A short survey is presented of attempts by Griffith and later investigators to establish a mathematical theory of perfectly brittle fracture. Equations arrived at in the course of this survey demonstrate the physical irrelevance of these attempts.

229. **Mechanism of Fracture of Glass and Similar Brittle Solids.** TAYLOR, N. W. *J. appl. Phys.*, 1947, **18**, 943–55. A theory is proposed which connects the stress required to break a brittle material in simple tension, with its duration of application. Definitions of 'brittle' and other materials are given. The slow process preceding fracture is shown to be the orientation of an atomic network contained in an elementary prism of atomic length. $r = \lambda o E/f$, where E is Young's modulus and λo is the critical elongation required for fracture. The possibility of viscous flow preceding fracture is discussed. 28 refs.

230. **On Cracks and Fissures. Their Physical Nature and Significance.** TERADA, T. *Rep. Inst. phys. chem. Res., Japan.*, 1931, **16**, 159–71. Rupture of a solid body under mechanical stress is a subject which has evaded attack by physicists. The literature is scanty. The author quotes: S. Suzuki, *Proc. phys.-math. Soc., Japan* (III), 1921, **3**, 168; Hirata, M., *Bull. Inst. phys. chem. Res., Japan*, 1929, **8**, 52 (European work is quoted here); Taguti, R., *Bull. Inst. phys. chem. Res., Japan*, 1931, **10**, 110. (1) Static and dynamic cracks. (2) Cracks and electrons. (3) Cracks and crystals. (4) Discontinuous absorption phenomena.

231. **Fatigue of Metals.** THORNTON, P. *Discovery*, 1955, **16** (9), 374–6. At inclusions or weaknesses, the local stress may be higher than the applied load, and be raised to a value in excess of the elastic limit. Plastic deformation and work hardening will then result and cause a more even distribution of the applied load. Every stress application causes some slip and work hardening, i.e. when the metal can deform no further. When fully work hardened, the absence of deformation results in crack formation in the locally brittle material. Once formed, it can grow by stress formation at the crack tip. Vibrations in metals always damp down. This implies that the mechanical energy is converted to another form, partly as heat. The residue may contribute to the rupture of the metal. Certainly metals behave in fatigue in accordance with their damping capacity.

232. **History of the Strength of Materials. (With a brief account of the history of the theory of elasticity and theory of structures.)** TIMOSHENKO, S. P. 1953, McGraw Hill Publishing Co., 439 pp. Chap. 12, section 73, pp. 358–62. Fracture of brittle materials. This section deals with the strength of glass, principally tensile strength. The tensile strength, of the order of 10^4 lb/sq. in., is found to be only 1/30 000 of the forces calculated to be necessary to disrupt the molecules. Griffith's theory concerning the effects of cracks and ageing is then discussed, and Griffith's experiments are quoted. The results are then quoted of the experiments of E. Joffe on rock salt crystals, where the large smoothing effect on tensile strength is so marked. If the strength of brittle materials is affected so much by the presence of imperfections, it seems logical to expect that the value of the ultimate strength will depend upon the size of the specimens and become smaller with increase of dimensions, since the probability of having weak spots is increased. Evidence in confirmation of this size effect was furnished by Weibull, in which it was found that the tensile strengths with geometrically similar specimens varied inversely as an exponential of the volume ratio. Foppl's work is then quoted, where the usually observed three dimensional compression as a result of friction on the surfaces under compression, was avoided by lubricating these surfaces with paraffin, so that on compression the cubical specimen failed by subdividing into plates perpendicular to the lubricated surfaces receiving the stress. The end effect can also be eliminated by compressing cylinders whose height is two or three times the diameter, and also by using conical plungers, whose angle is equal to the angle of friction.

233. **The Fracture of Metals.** TIPPER, C. F. *Metallurgia, Manchr.*, 1949, **39**, 133–8. A survey of the subject.

234. **Effect of Capping Methods and End Conditions before Capping, upon the Compressive Strength of Concrete.** TROXALL, G. E. *Proc. Amer. Soc. Test. Mater.*, 1941, **41**, 1038.

235. **Line Structure in Fracture Surfaces.** WALLNER, H. *Z. Phys.*, 1939, **114**, 368–78. The intersecting curved lines on the fracture surfaces of glass rods are discussed. It is suggested that these might provide a means of estimating rate of propagation of the fractures, but quantitative data are not yet forthcoming.

SURFACE PHENOMENA: SURFACE ENERGY

236. **Crushing of Single Particles of Crystalline Quartz. Calculated values for Surface Energy.** AXELSON, J. W. and PIRET, E. L. *Industr. Engng Chem.* (*Industr.*), 1950, **42** (4), 665–70.

	ergs/ sq. cm	*Method*
Edser, 1922	920	Van der Waals equation. Density. Cubic expansion of quartz.
Martin, 1926	510	Energy to convert silica to gas.
Fahrenwald *et al.*, 1931	995	Modification of Martin's method.
White, 1943	2300	Breaking strength, specific heat, coeff. of expansion, distance between planes.

Axelson and Piret used 980 as an arbitrary value.

237. **Aggregation and Flow in Solids.** BEILBY, G. 1921, MacMillan, London. The author puts forward the view that in operations such as polishing, cutting, grinding, the surface of particle or material acquires different properties from those of the bulk. This 'Beilby Layer' may be a vitrified or amorphous layer.

238. **Effects of Imbibition: Influence of Liquids on the Breaking Strength of Solids.** BENEDICKS, C. *Chim. et Industr.*, 1948, **30**, 103; *Rev. Métall.*, 1948, **45**, 9–18. Tests were made on the following systems: Glass in water, ethanol and turpentine; chromium

steel in aqueous caustic soda; zinc in mercury. A theoretical explanation for the reduction in breaking strength on immersion is proposed. The effect, however, is sometimes to increase the breaking stress. The entry of liquids into surface cracks affects the breaking strength, sometimes by increasing and sometimes by decreasing it. Benedicks proposes an explanation based on the effect of the liquid on the cohesion of the solid molecules at the crack tip.

239. **Measurement of the Surface Tension of Solid Substances.** BERDENNIKOV, W. P. *Phys. Z. Sowjet.*, 1933, 4, 397–419. The surfaces of metals, glass, quartz, etc., have their characteristic properties. These are determined often by mechanical and thermal methods and sometimes by chemical means. The method for thin glass plates here described is to cut the surface of a very thin slip so that the crack extends through the thickness along a part, say 10%, of the width, and to observe the force required to make an initial extension of the crack. Contact with a liquid lowered the surface tension, particularly with polar liquid.

240. **The Surface Tension of Alkali Halides.** BIEMULLER, J. *Z. Phys.*, 1926, **38**, 759–71. The influence of the deformability of ions on surface energy is investigated for sodium chloride type crystals. Born's formulae are examined with a view to obtaining a general solution of electrostatic surface energy problems.

241. **The Surface Energy of Crystals and its Influence on Crystal Forms.** BORN and STERN. *S.B. preuss. Akad. Wiss.*, 1919, **48**, 901.

242. **The Surface Energy of Barium Sulphate.** BRUZS, B. *J. phys. Chem.*, 1930, 34, 621–6. A calorimetric method, with diagram, is described for a set of reactions with barium chloride and manganese sulphate and the heats of reaction observed. Surface tension and surface energy have been determined, the latter up to 2200 cal/mol.

243. **Physico-Chemical Studies on Dusts, Pt. 1. A High Solubility Layer on Siliceous Dust Surfaces.** CLELLAND, D. W., CUMMING, W. M. and RITCHIE, P. D. *J. appl. Chem.*, 1952, 2 (1), 31–41. The effect of pre-treatment with various solutions, acids and buffers upon the solubility of siliceous dusts has been investigated, and the existence of a high solubility layer has been demonstrated. Comparative solubility data have been obtained for three silicas, olivine and felspar. The effect of additions of metallic aluminium has been investigated. 12 refs.

244. **Physico-Chemical Studies on Dusts, Pt. 2. The Nature and Regeneration of the High Solubility Layer on Siliceous Dusts.** CLELLAND, D. W. and RITCHIE, P. D. *J. appl. Chem.*, 1952, 2 (1), 42–8. It is shown that the layer is not a hydrated silica but a vitreous layer formed during crushing and grinding. The resulting reduction in density is attributed to partial conversion to vitreous silica and not to other crystalline modifications. 13 refs. For Pts. 3 and 4, *see under* Cumming, *et al.*, Dust Hazards.

245. **The Effect of Boundary Distortion on the Surface Energy of a Crystal.** DENT, B. M. *Phil. Mag.*, 1929, **8** (7), 530–8. It is shown that for a series of alkali halide crystals, it is the deformability of the surface ions which largely controls the distortion at the surface.

246. **The Solubility and Surface Energy of Calcium Sulphate.** DUNDON, M. E. and MACK, E., Jr. *J. Amer. chem. Soc.*, 1923, **45**, 2479–85. Hulett's work (*Z. phys. Chem.*, 1901, **37**, 385) is repeated and the method extended to several other substances to obtain reliable values for their surface energy. A discussion on errors of calculation of surface energy found in the literature is given. (Calcium sulphate tends to become dehydrated during grinding.) This factor is of importance in relation to the solubility of finely powdered calcium sulphate. Working with particles 0·2 mu and 0·5 mu in diameter a value of 370 ergs/sq. cm has been calculated for the surface energy of the dihydrate. A theoretical discussion precedes the experimental part.

247. **The Effect of Water Adsorption on the Strength of Kaolinite Compacts.** DOLLIMORE, D. and GREGG, S. J. *Trans. Brit. Ceram. Soc.*, 1955, **54** (5). Compacted cakes of

calcium carbonate at 9980 lb/sq. in., and kaolinite 3260 lb/sq. in., were found to diminish in breaking strength proportional to the vapour pressure in the case of kaolinite and suddenly in the case of calcium carbonate, when exposed to increasing vapour pressures. A decrease of surface energy is involved by penetration of water vapour into the surface cracks (as with glass) and thus a decrease in strength. The surface energy increases on removing water vapour, due evidently to sealing up the cracks by solution.

248. **The Concentration of Minerals by Flotation.** EDSER, E. *Advanc. Sci., Lond.*, 1922, 281. The author gives the surface energy of quartz as 920 ergs/sq. cm, derived from the use of Van der Waals equation, the density and thermal cubical expansion of quartz. (Cf. Martin's calculated value 510 ergs/sq. cm, based on the assumption (dubious) that the work required to reduce quartz sand to the size of the molecule would be the same as that required to convert silica to a gas.) (Both values are probably too low; Fahrenwald, 1931.)

249. **Colloid and Capillary Chemistry.** FREUNDLICH, H. 1926, Methuen & Co., Ltd., London. On pp. 102 and 155 *et seq.*, a summary of the work on surface energy of solids by indirect methods is given.

250. **Physico-Chemical Studies on Dusts.** GIBB, J. G., RITCHIE, P. D. and SHARP, J. W. *J. appl. Chem.*, 1953, 3 (5), 213–8. Amorphous layer on the surface of silica particles. *See under* Size and Surface Determination.

251. **Effect of Adsorption on the Strength of Brittle Solids.** GREGG, S. J., DOLLIMORE, D. and DESAI, A. (University College, Exeter.) *Nature, Lond.*, 29 Oct. 1955, **176** (4487), 819–20. Conference of the British Society of Rheology, Exeter, Sept. 1955. After summarizing the general theory of the subject, recent experimental work on the strength of compacted discs of compressed powders, broken in vacuo and in controlled atmospheres, was described. Adsorption isotherms had been prepared for discs of calcium carbonate, kaolin and boric acid powders. Strengths were measured under states of adsorption and desorption and graphs showed the relation between strength and surface energy as the latter diminishes by adsorption of water vapour. The effect was not produced by adsorption of benzene vapour, although the latter is strongly adsorbed. The difference in behaviour is attributed to the larger size of the benzene molecule, which therefore cannot enter the cracks as done by water vapour. *See also under* Dollimore.

252. **Determination of the Specific Gravity of Molten Salts and of the Temperature Coefficients of their Molecular Surface Energy.** JAEGER, F. M. and KAHN, J. *Proc. Acad. Sci. Amst.*, 1916, **19**, 381–97. Methods are described, especially the hydrostatic method for high melting point solids. Limitations are mentioned, and results tabulated for a large number of salts.

253. **Deformation and Strength of Crystals.** JOFFE, A. *Z. Phys.*, 1924, 286–302. A rock salt crystal tested while under water was found to have a tensile strength approaching that calculated from theory, i.e. 16 000 and 20 000 lb/sq. in. respectively. *See* No. 93.

254. **The Calculation of the Surface Energy and the Energy of Twinning of Calcite.** KANER, F. *J. exp. theor. Phys.* (*Zh. eksp. teor. Fiz.*), 1939, **9**, 212. The only values for surface energy which yield efficiencies at all approaching those determined from the associated energy values are the author's figure for Calcite and the Kuznetsov and Kudryasheva figure for rock salt, where the determinations were carried out as with a ball mill method.

255. **Experimental Determination of the Specific Surface Energy of Rock Salt Crystals.** KUZNETSOV, V. D. and KUDRYASHEVA, —. *Z. Phys.*, 1927, **42**, 302–10. The specimen is mounted on a vertical rigid surface. A safety razor blade in a horizontal position is set to touch the crystal face and a rectangular weight supported by four

threads supplies a blow after being swung from a known distance. The calculated energy of the blow is divided between the surfaces produced. Alternatively the blade is fixed to the swinging weight, but this is found less satisfactory. Surface energy values varied from 1·5 to 56 ergs/sq. mm.

256. **The Specific Energy and Heat of Solution of Solid Sodium Chloride.** LIPSETT, S. G., JOHNSON, F. M. G. and MAASS, O. *J. Amer. chem. Soc.*, 1927, **49**, 925–43, 1940. A new type of calorimeter is described for small quantities of material to determine the heat of solution from high to very low concentrations accurately. The calculations are based on the measurement of the heat of solution of ordinary crystalline sodium chloride and that of finely divided salt of the same concentration. Factors influencing precision are discussed.

257. **The Surface Energy of Solid Sodium Chloride. III. The Heat of Solution of Finely Ground Sodium Chloride.** LIPSETT, S. G., JOHNSON, F. M. G. and MAASS, O. *J. Amer. chem. Soc.*, 1928, **50**, 2701. Described results when NaCl was ground in an agate mortar and air elutriated. (Contained no SiO_2 by analysis.) Particle size was measured by means of photomicrograph. 'The heat of solution was determined at 25° at a concentration of 4·62% with three different samples of salt.'

Heat of solution of finely ground NaCl

Sample	Heat of solution (calories) per mol.)	Difference in heat of solution (calories per mol.)	Diameter of average particle (mu)
1	−903·7	24·9	1·3
2	−903·6	25·0	1·2
3	−887·9	40·7	1·4

Column 3 gives 'the difference between the heat of solution of coarsely ground sodium chloride (928·6 calories/mol.) and the finely ground salt as measured'. From previous work sublimed salt 1·3 mu diameter 'would have approximately a heat of solution only 11 calories less than that of coarse salt'. The large difference is attributed to the uneven surface of ground NaCl, microscopic examination showing sublimed salt to be regular in shape and to have smooth surfaces.

258. **Surface Energy Investigations.** MARTIN, G., *et al.* *See under* Fundamental Aspects, General Papers.

259. **The Surface Tension of Solid Bodies.** OSTWALD, W. *Z. phys. Chem. A*, 1900, **34**, 495.

260. **Solid Surface Energy and Calorimetric Determination of Surface Energy Relationships for Some Common Minerals.** SCHELLINGER, A. K. *Min. Engng, N.Y.*, 1952, 4 (4), 369–74. The new surface formation as determined by the Brunauer–Emmett–Teller adsorption isotherm method was equated to the net energy input determined in a lead shot tumbling mill calorimeter. The plotted graphs were found to be straight lines passing through the origins, the slope varying for each mineral. The minerals used were: quartz, pyrite, calcite and sodium chloride. In addition the energy per unit surface area produced was found to be in order of the hardness of the minerals. Theoretical surface energies, 107 000, 60 000, 32 400 and 26 100 for the minerals resp. were very much higher than the theoretical values. No reason was found. Agreement was much closer when surface tensions (of carbonates and oxides) were calculated from vapour tension measurements, based on the use of the Gibbs-Thomson equation for the enhanced vapour pressure of particles of less than one micron. The surface tensions were found to be of the order of 100 000 to 750 000 dynes/cm. 19 refs. *See also*

Tzentnershver. K. L. Sutherland, *J. Aust. chem. Inst.*, 14 July 1947, states that surface energies for ductile materials such as copper and gold were found experimentally to be much higher than for quartz and pyrites, but casts doubt on their validity.

261. **A Contribution to the Study of Flotation.** SULMAN, H. L. *Trans. Instn Min. Metall., Lond.*, 1919–20, **29**, 63. Every increase in surface area of a solid is represented by a corresponding increase of surface energy and in the creation of a fresh surface heat is also absorbed. If the surface be enlarged adiabatically a liquid will be cooled.

262. **The Influence of Particle Size upon the Dissociation Pressure of Solid Substances.** TZENTNERSHVER, M. and KRUSTINSONS, J. *Z. phys. Chem.*, 1927, **13**, 187–92. The dissociation pressure of very fine carbonates and oxides enables an estimate of its surface tension to be made.

ABRASION GRINDING

263. **Abrasion Resistance and Surface Free Boundary Energy of Solid Substances.** ENGELHARDT, W. von. *Naturwissenschaften*, 15 Oct. 1946, **33**, 195–203; *Industr. Diam. Rev.*, 1950, **9**, 366–9; **10**, 19–23. A standard method of testing abrasion characteristics is described, and consists of estimating the loss in weight of the prepared sample when pressed under a known load on to a revolving steel disc, abrasive powder lubricant being added at known rates. A simple formula is derived equating the loss in weight with other data. The relation between tensile strength and abrasion resistance is discussed and found from the data to be approximately linear. The relation between hardness and tensile strength is discussed. With the former, deformation is the controlling factor; with the latter it is attrition of a rigid substance, and this is related to tensile strength. The very large variations in abrasion strength in presence of various lubricants is discussed, being, e.g., nearly double for quartz and water than for quartz and oleic acid. The need for careful choice of lubricant is pointed out. Its influence in all kinds of comminution, grinding and abrasion processes is pointed out; the author claims that the choice of coolant or lubricant should be made on theoretical grounds in relation to surface energy of the material and gives examples of such choice. (*Industr. Diam. Rev.*, 1949, 369.) Smekal, 1931, pointed out that strength properties, owing to the integration of the s.f.b.e. into strength values, must be dependent on the surrounding medium. Smekal also gives a complete survey of previous experimental data on this subject (Kohesian der Festkorper in *Handbuch der Mechanik*, 1931, Anerbach and Hart, 4/2, 1–153). This is supplemented by the work of Rehbinder and other Russian investigators who have shown that the surrounding medium is not only important in simple tensile tests, but also in mechanical comminution, scratching, drilling, etc. By the pendulum sclerometer (with steel points) he demonstrated the hardness and wear variations in different fluids. It is emphasized that following the work of Rehbinder the effect on comminution of solids of suitable fluids has been thoroughly investigated in Russia with a view to industrial application. Hints are found in Rehbinder's work, 1936. *Bull. Akad. Sci. U.R.S.S.*, Chem. Series (*Izv Akad, Nauk S.S.S.R.*, Seriya Khim.), 1936, 639–707, 740. From surface energy considerations, and abrasion test data, it is considered that the s.f.b.e. when grinding or drilling solids exceeds the work necessary for forming one surface unit by a factor of 10^4 or 10^5. Berdennikov, *Phys. Z. Sowjet.*, 1933, **4**, 397. The relation of surface free boundary energy to fluids in contact, is discussed at length, and it is regarded as certain that a wider knowledge of the factors which influence the s.f.b.e. of a solid substance with regard to a fluid must be of technical interest. By the use of suitable fluids, capacity of comminution devices can be increased twice or more as compared with water, i.e. by using a liquid giving a low s.f.b.e. 23 refs.

264. **The Surface Energy of Solids. Chap. 4. Abrasion Grinding and Drilling.** KUZNETSOV, V. D. 1954. Gosudarstvennoe Izdatelstvo Tekhniko-Teoreticheskoi Literatury, Moscow. English translation from the Russian, 1957, H.M. Stationery

Office, 8*s*. 6*d*. net. Abrasion grinding and drilling can be used as a method of determining surface energy of solids, being based on a relatively solid, theoretical and experimental basis. It also gives accurate relative values of the surface energy of crystals. Experimental verification so far has been obtained only on crystals and polycrystals of alkali halides. The main part of the energy loss on grinding, 84–70% ,is converted to heat spent on elastic deformation, 16–30% is spent on absorbed energy, i.e. on plastic deformation; only a negligible fraction of the energy, 10^{-4} to 10^{-5}, is spent on increase of surface energy. An accurately calibrated calorimeter was used for the determinations. Abstracted in *Industr. Diam. Rev.*, 1955, **15** (178), 169–70. The abstract does not give the method for obtaining direct values for surface energy.

265. **Regularities of Grain-size Distribution in Abrasion Processes as illustrated by the Friction Milling of Coal Briquettes.** RAMMLER, E. *Verfahrenstechnik*, 1940, 6; *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1941, **5** (2), 23. The investigation of abrasion milling, without any grinding, on various types of coals showed that the grain-size distribution follows the exponential law: $R=100e^{-bx^n}$, where R=residue on the screen, x=grain size and b and n are constants. For all but lignite briquettes it was found that $n=1$. As soon as grinding occurs simultaneously with abrasion, the law does not hold. The experimental apparatus, data, diagrams, and figures are given. In calculating the surface area, it is now the tendency to extend the arbitrary boundaries and include the coarser and finer end fractions even to 0·1%.

266. **Free Boundary Surface Energy and Resistance to Grinding of Glass.** RAMMSAUER, R. *Kolloidzschr.*, 1951, **121**, 71–4. Measurement of the abrasion of glass spheres was carried out by measuring the loss in weight of ten glass spheres of about 0·5 cm diameter in a ball mill over a given time, when rolled with 5 g of various hard abrasives and 20 c.c. of various liquids or solutions. The conclusions of W. von Engelhart, *Naturwissenschaften*, 1946, **33**, 195, are discussed in relation to present conclusions. These are that the abrasion resistance of a solid body depends not only, as formerly accepted, on the influence of the liquid on boundary surface energy of the abraded body, but at the same time on the influence of the liquid on the size of particles abraded. Determinations of abrasion resistance do not lead to definite conclusions on the surface adsorption of liquid, and abrasion measurements do not afford a guide as to free surface energy. Tabular representation of results. No refs.

267. **A Physical Examination of the Empirical Laws of Comminution.** WALKER, D. R. and SHAW, M. C. *Min. Engng, N.Y.*, 1954, **6**; *Trans. Amer. Inst. min. (metall.) Engrs*, **199**, 313–20; discussion 1106–8. The laws of Kick and Rittinger are explained as functions of particle size with metal cutting theory. Comminution is shown to be basically the same process as metal grinding. The machine shop type of grinding operation is used to study mineral crushing. Evidence indicates that plastic flow occurs in comminution of materials ordinarily considered brittle. For this reason there is little difference between comminution processes such as ball milling and machine grinding, and thus it would appear that the machine grinding technique described here offers a precise means for evaluation of grinding characteristics of various materials. In this operation, the energy consumed in particle formation can be studied under conditions that provide particles of essentially constant size. Analysis of data so obtained shows that Kick's law holds for very fine grinding, i.e. to one micron. Rittinger's law is found to hold when the range of size is relatively small. When the data cover a considerable range, R.'s law predicts too small a size effect, and there is no apparent physical basis for R.'s prediction that is in agreement with current concepts. 12 refs.

GRINDING KINETICS: EQUILIBRIUM THEORY

268. **Effect of Grinding on Particles.** BRADSHAW, B. C. *J. chem. Phys.*, 1951, **19** (8), 1057–9. When a material is ground for an indefinite period, a stage is reached when

further grinding produces no further change in the particle size distribution. Relatively small particles disappear by union either with one another or with larger particles. The limiting distribution of particle sizes resulting from long-continued grinding is dynamic rather than static. White blasting sand was used and an increase of particle size and grittiness was obtained. The experiments of Bowden on frictional effects are discussed, and energy considerations involved in the observed shape and size changes of nickel powder on exposure to an electron beam are put forward. The author concludes from the work of Bowden, *Proc. roy. Soc. A*, 1939, **169**, 371, that many particles of 10 millimicron size become united to larger particles when rubbed between them, and so disappear from the distribution curve.

269. **Comminution as a Chemical Reaction.** GAUDIN, A. M. *Min. Engng, N.Y.*, 1955, 7; *Trans. Amer. Inst. min. (metall.) Engrs*, **202** (6), 561–2. A tabulated classification of crystals is presented. Some types consist of groups of atoms sharing electrons within, but not between the groups. Where comminution involves severance of ionic or covalent bond, chemical reaction has taken place. With extremely fine fragments cold recombination is possible, thus limiting the proportion of extremely fine particles in the product. Much work has yet to be done in this field. 1 table, 4 refs.

270. **The Kinetics of Grinding Processes.** HUTTIG, G. F. *Z. Elektrochem.*, 1953, **57** (7), 534–9. (1) A review of grinding functions. A discussion as to how these, in the light of the important contribution of O. Theimer, are capable of leading to an adequate description and evaluation of grinding processes and phenomena. (2) The practical application of these functions, with graphic illustration, to reduction processes using fine and coarse fractions of quartz sand. (3) The consideration of ideal limits of reduction processes. (4) A contribution to the problem of orders of reaction in grinding kinetics.

271. **The Probability Theory of Wet Ball Milling and its Application.** ROBERTS, E. J. *Min. Engng, N.Y.*, 1950, **2**; *Trans. Amer. Inst. min. (metall.) Engrs*, **187**, 1267–72. *See under* Ball Mills.

272. **Recent Results in the Field of Grinding Technique.** SALES, H. and HUTTIG, G. F. *TonindustrZtg*, 1954, 186. Report of a lecture delivered at the Fourth Stone and Earth Conference, held 29–30 April 1954 at Aachen. Following the evaluation of milling tests on quarry sand, it is deduced that the grinding of brittle materials can be treated as a chemical reaction of the first order. The values of the velocity curve depend on the characteristics of the material, of which bond strength is overriding, and on the actual grinding process. Assuming that the size of the material is very much smaller than the grinding media, one can assume that the velocity constant for all particle distributions is the same. The 'Absolute Velocity Constant' can only be observed when no fresh material is added or finds its way in during the operation. With all ranges of particles to which larger particles are fed during milling, the 'Effective Velocity Constant' can be evaluated. This increases with increase in particle size, and only reaches the value of the 'Absolute Velocity Constant' with coarse particles. The conclusion is that all particles of a given class disintegrate in the same manner.

273. **The Origin of Particle Size Distribution and the Influence of Time upon it in the Disintegration of Hard Materials.** SMEKAL, A. *Chem.-Ing.-Tech.*, 1956, **28**, 213.

274. **The Statistical Mechanics of Crushing Processes.** THEIMER, O. *Kolloidzschr.*, Aug. 1952, **128** (1), 1–6. The author deals with the size equilibrium reached after a sufficient period of grinding and suggests that this equilibrium may be analogous to other equilibria such as thermal equilibria. If so, then various mathematical devices can be applied and the author derives the appropriate theoretical equations. He leads to the conception of 'mechanical temperature' and deals with the phenomena by methods well-known in dealing with the thermodynamics of gases, and it is possible to derive the equilibrium particle size distribution of the ground material. The equation is similar in form to the Rosin-Rammler equation. (*Kolloidzschr.*, 1934, **67**, 1.)

275. **The Evaluation of Grinding Experiments with the Help of Grinding Equations.** THEIMER, O. and MOSER, F. *Kolloidzschr.*, 1952, **128** (2), 68–74. 4 refs.

276. **Kinetics of Crushing Processes.** THEIMER, O. *Kolloidzschr.*, 1953, **132** (2/3), 134–41; **133** (1), 44–50. The author attempts to develop the kinetics of crushing in formal analogy to chemical reaction kinetics. Velocity coefficients are introduced and orders of reactions are defined by equations. Two practical examples are discussed. 4 illustrations, 14 refs.

AGGLOMERATION

277. **How and Why Solids Agglomerate.** LUDWIG, K. *Chem. Engng*, Jan. 1954, 156–9. Some of the fundamental principles of agglomeration are set forth. The packing of particles of uniform and different sizes is described, and is illustrated by the quality and strength of extruded products. The effects of plasticity and surface tension are considered. Materials in the ceramic, mineral and chemical industries are considered.

278. **Causes of Granulation of Powders.** VOYUTSKII, S. S., ZAIONCHKOVSKI, A. D. and RUBINA, S. I. *C.R. Acad. Sci. U.R.S.S.* (*Dokl. Akad. Nauk S.S.S.R.*), 1951, **78**, 307–10; *Chem. Abstr.*, 1951, 7846. Fine lamp black powder was granulated by tumbling in the presence of 'germs', i.e. rolled flakes of lamp black (or other materials). That the granulation is not due to the linking of chain-like or dendritic particles follows from the observation that preliminary thorough grinding in a ball mill not only does not prevent granulation, but improves it somewhat. Adsorbed gases counteract granulation; in vacuo it is 3–4 times as fast as in air. Chalk and kaolin could be granulated in the same way, but not sulphur or graphite.

NUCLEATION THEORY

279. **Nucleation Phenomena.** *Industr. Engng Chem.* (*Industr.*), 1952, **44** (6), 1269–1338. A symposium of seventeen papers is presented under Theory and Review, Nucleation in gases—liquids—and solids. The latter includes a paper by W. George on 'Nucleation and growth of flow and fracture markings'.

280. **Nucleation and Growth of Flow and Fracture Markings.** GEORGE, W. *Industr. Engng Chem.* (*Industr.*), 1952, **44** (6), 1328–31. A symposium on Nucleation Phenomena. Macroscopic observations of the spatial development of localized plastic flowing and fracturing in polymeric solids (and metals) are used to suggest 'models' of the physical character of microscopic processes of plastic flowing. The nature of delayed yielding in metals and polyamides is reviewed. Special emphasis is placed upon the advance nucleation of macroscopic flow and fracture elements in the region of stress concentration in advance of the primary flow or fracture event. This effect is illustrated in the growth of fatigue and creep fracture. Fracture pairs and showers are illustrated. If a similar process does exist on the microscopic scale it may well be the major source of slow speed dislocation multiplication. 23 refs. (The existence of a time interval between application of load and response of the specimen was first clearly demonstrated by Clarke and Wood, 1949, although it was observed by Andrade as early as 1911.)

281. **From the Nucleation Viewpoint. New Approach to Reduction Problems.** SIMMONDS, W. H. C. *Chem. Engng News*, 23 May 1955, **33**, 2206. No one has yet measured in the same experiment all the four quantities involved in size reduction: i.e. work input, heat evolved, increase in surface energy, and the energy liberated within the system. The rate controlling step may be the formation of crack nuclei or the growth of fractures. It is suggested that the formation of crack nuclei be treated as an activated rate process and the resulting subdivision as an energy distribution problem, the latter being an irreversible process.

282. **Size Reduction as a Nucleation Process.** SIMMONS, W. H. C. *Chem. Engng*

Progr., 1956, **52** (4), 139–42. Size reduction is associated with diverse operations such as boiling, dropwise condensation and crystallization, in that they all represent the formation of new interfaces. These involve the formation of a nucleus and then a growth process. The concept is discussed and a theoretical approach is made.

THEORETICAL PAPERS: VARIOUS

283. **The Shapes of Particles from Dielectric Constant Studies of Suspensions.** ALTSHULLER, A. P. *J. phys. Chem.*, 1954, **58**, 544–7. The mathematical results of the present investigation indicate that measurements of dielectric constants of dilute suspensions may be employed to obtain the average shapes of the suspended particles. Measurements on suspensions of particles completely oriented with respect to the electric field by some external force should be particularly useful.

284. **The Mechanism of Dilatancy.** ANDRADE, E. N. da C. and FOX, J. W. *Proc. phys. Soc., Lond.*, 1949, **62B**, 483–500. The movement of dry particles under load was investigated by means of the effects of the pressure of a piston on a two-dimensional array of uniform cylinders. The occurrence of slip planes is demonstrated and similarity between the movement of the cylinders and of sand under load is illustrated.

285. **The Physics of Wind Blown Sands and Desert Dunes.** BAGNOLD, R. A. 1941, Methuen & Co., London. 256 pp. An attempt to explain on a basis of experimental physics some of the many strange phenomena produced by natural movement of sand over the dry land of the earth. 16 plates, 84 diagrams.

286. **Release Analysis. A New Tool for Ore Dressing Research.** DELL, C. C. Institution of Mining and Metallurgy, Paper No. 8, 1953. Analysis by flotation in successive short times (1 min) using appropriate media. The method consists in working the mill to give an ore particle size which upon subsequent flotation gives the best recovery of copper rich ore. Avoids unnecessary overgrinding and indicates when regrinding of tailings is required.

287. **Mineralogical Hardness Scale.** DMITRIEV, S. D. *Rec. Russ. miner. Soc.* (*Zapiski vsesoyuz. mineral obshchestva*), 1949, **78** (4), 241–52. A new mineralogical hardness scale is proposed, to replace the old Mohs' scratch hardness scale. The hardness of all materials is expressed in terms of resistance to penetration by a diamond pyramid as kg/sq. mm. The formula for microhardness is given and the values for some common minerals are tabulated. This indentation hardness test has obvious advantages, since the scale is the same as is adopted for metals. A hardened steel would give a reading in the range 500–1000.

288. **Collisions through Liquid Films.** EIRICH, F. R. and TABOR, D. *Proc. Camb. phil. Soc.*, Oct. 1948, **44**, 566–80. A simple mathematical analysis is made of the hydrodynamic behaviour of a liquid layer interposed between two colliding surfaces.

289. **A Study of the Effect of Grinding on Kaolinite by Thermo-gravimetric Analysis.** GREGG, S. J. *Trans. Brit. Ceram. Soc.*, 1955, **54** (5), 257–61; *J. appl. Chem.*, 1954, **4** (11–12), 631–2, 666–74. *See under* Ceramics.

290. **The Study of Isochromatic Lines in Transparent Models subjected to Extreme Plastic Deformation.** GUBKIN, S. I. and DUBROVSKII, S. I. *C.R. Acad. Sci. U.R.S.S.* (*Dokl. Akad. Nauk, S.S.S.R.*), 1953, **88** (5), 799–802. The paper includes some discussion of the phenomena in elastic and elasto-plastic materials. Photographs.

291. **The Pulverization Wave (In a Coal Seam).** KHRISTIANOVICH, S. A. *Bull. Akad. Sci. U.R.S.S.*, tech. sci. (*Izv Akad. Nauk, S.S.S.R.*, O.T.N.), 1953 (12), 1689–99. Translation available from D.S.I.R. Ref. CTS 132, price £1 2*s*. net.

292. **Surface Investigation with the Geiger Counter in Reduction Processes.** KRAMER, J. *Ber. dtsch. keram. Ges.*, 1953, **30**, H. 9. The rate of emission of 'Exo-elektronen' from newly formed surface of small samples of inorganic materials taken at intervals

during grinding in a small ball mill rises evenly to a maximum and falls evenly again. Since it is possible to choose a point on the falling rate part of the curve where further grinding would be unprofitable, it would suggest that this rapid method of test might be adapted to practical needs. The more well-known methods of producing surface emission are discussed and results are presented graphically. 14 refs. A brief account by author in *TonindustrZtg*, 1953, 77, 178. (At Verein Deutsche Ingenieur Staubtechnik Tagung in Essen, March 1953.)

293. **Surface Investigation with the Emission Counter.** KRAMER, J. *TonindustrZtg*, May 1953, 77 (9/10), 178. Exo-elektronen in grinding processes with examples. These slow electrons are not significant in themselves since they are few and variable in number, but they afford a means of detecting changes in surface structure. For instance the progress of size reduction can be followed. Inclusions of non-metallic ingredients with metals can be detected after submission to X-rays, and changes in surface from various causes can be detected.

294. **Stress Rupture of Heat Resisting Alloys as a Rate Process.** MACHLIN, E. S. and NOWICK, A. S. *Trans. Amer. Soc. mech. Engrs*, 1947, **172**, 386–412 (*Tech. Ppr* No. 2137). During a stress rupture test, a tensile specimen is held under a constant load until it breaks. Discussion. 8 refs.

295. **The Atomic Constitution of a Crystal Surface.** MADELING, E. *Phys. Z.*, 1913, **14**, 729; 1919, **20**, 494–6. A mathematical analysis of the atomic constitution of sodium chloride type crystal.

296. **Measurement of Relative Hardness of Fine Powder Particles.** MATTHEWS, J. B. *J. Inst. Met.*, Feb. 1953, **6**, 279–85. A method of assessing the relative hardness of fine particles is described. The powders are dropped on to an inclined polished surface and the change in specular reflectivity of the surface is measured. Theoretical considerations derived assume spherical particles in a narrow size range.

297. **The Fracture Surfaces of Finely Powdered Minerals.** MELDAU, R. and ROBERTSON, R. H. S. *TonindustrZtg*, Dec. 1952, **76**, 365–8. The characteristics of powders are discussed and fully illustrated by photographs. The type of breakage is classified into (a) waxy, (b) rupture, (c) amorphous. Recrystallization during wet grinding, slippage of crystal planes, shapeless breakage and the order of size of the particles are discussed. Where internal tension exists the size may reach down to 5–10 millimicrons but in absence of tension, not beyond 30–100 millimicrons. For instance, quartz which has been under pressure in the earth can be crushed to a much finer degree than the usual variety. In discussing the vitreous layer on crushed particles, the author concludes that the absence of this (the Beilby) layer would lead to a much larger proportion of extremely fine particles. Work is going on elsewhere to find if the Beilby layer can be made amenable to investigation as is the bulk of the particle. A considerable portion of the paper is devoted to a review of the work or conclusions of some 20 authors, seriatim, concerned with the surface characteristics of crushed particles. 18 refs.

298. **Resistance to Indentation and Strength of Plastic Materials.** PRANDTL, L. *Z. angew. Math. Mech.*, 1921, **1** (1), 15–20. A geometrical and mathematical analysis of indentation phenomena, with reference to hardness testing.

299. **A Simple Theory of Static and Dynamic Hardness.** TABOR, D. *Proc. roy. Soc. A*, 1947–8, **192**, 247–74. The theory is derived after a consideration of elastic recovery of the metal after static or dynamic ball indentation (with resulting shallowing of the indentation).

300. **A Physical Explanation of Empirical Laws of Comminution.** WALKER, D. R. and SHAW, M. C. *Min. Engng, N.Y.*, 1954, **6**; *Trans. Amer. Inst. min. (metall.) Engrs*, **199** (3), 313. Seeks to explain the Kick and Rittinger laws as function of particle size with a metal cutting theory, with which comminution is basically the same process.

301. **The Measurement of the Electrical Resistance of Powders.** WARTENBERG, H. von. *Z. angew. Phys.*, 1953, 5, 291–2; *Chem. Zbl.*, 26 Jan. 1955, **126** (4), 745. The powder is immersed in an electrolyte whose conductivity is systematically altered. When the powder addition fails to change the conductivity of the electrolyte, the conductivities of the two are equal.

302. **The Relation of Crystal Lattice Discontinuities to Mineral Dressing.** WELCH, A. J. E. *Recent advances in Mineral Dressing.* 1953, Institution of Mining and Metallurgy. Mosaic structure in crystals. The nature of crystal faces, edges and corners. Adhesion between crystalline solids. Energy relationships in solids containing lattice defects. 'Active solids.' Adsorption at the discontinuities.

GLASS: STRENGTH AND SURFACE PHENOMENA

303. **Strength of Glass and Other Fibres.** ANDEREGG, F. O. *Industr. Engng Chem. (Industr.)*, 1939, **31** (3), 290–8; *Chem. Abstr.*, 1939, **18** (9), 241. The author obtained results similar to A. A. Griffith in 1920 in the variation of tensile strength with diameter. 15 refs.

304. **Surface Cracks in Glass.** ANDRADE, E. N. da C. and TSIEN, L. C. *Proc. roy. Soc. A*, 1937, **159**, 346–55; *Ceramic Abstr.*, 1937, **16** (9), 272. The rupture strength of solids is only about 1/1000 of the theoretical strength. The author refers to Griffith cracks and shows that the attack of hot sodium vapour develops on the surface of hard glasses a series of fine lines, which by their nature, position and direction cannot be attributed to mechanical scratches. These are not found with glass freshly drawn at high temperature, but are frequent when the glass has been kept for some hours. The arrangement of the lines suggests that they arise in directions normal to the principal stresses (tensions). These Griffith cracks cannot be brought to light by hydrofluoric acid, as can scratches and drawing marks. Etching with hot sodium vapour may be of value in investigating the structure of glass. 7 refs.

305. **The Scratch Resisting Power of Glass.** BAILEY, J. *J. Amer. ceram. Soc.*, 1937, **20** (2), 43–52. The method of test consisted of rolling a $\frac{1}{8}$-in. diameter steel ball over the surface with increasing pressure. The pressure for the first conchoidal break was used as a measure of hardness. The reasoning for this is given. Illustration and diagram of apparatus. 6 refs.

306. **Attempt to Correlate Some Tensile Strength Measurements.** BAILEY, J. *Glass Ind.*, 1939, **20** (1), 21–5; (2) 59–65; (3) 95–9; (4) 143–7; *Ceramic Abstr.*, 1940, **19** (4), 89. Evolved a strength theory on the probability of a flow being present in the highly stressed surface. These weak links have a statistical variation in strength.

307. **Phenomenon of Rupture and Flow in Solids.** GRIFFITH, A. A. *Phil. Trans. A*, 1920, **221**, 163–98; Abstract in *J. Amer. ceram. Soc.*, 1921 4 (6), 513. Griffith found that the tensile strength of glass fibres from 1 to 4 and 40 thousandths in. in diameter varied in tensile strength from 491 000 to 134 000 and 117 000 lb/sq. in. respectively. (Cf. Preston's rebuttal. 1954.) So did Plummer, 1938, and Anderegg, 1939. *See under* Mechanism of Fracture for fuller abstract.

308. **The Effect of the Surrounding Atmosphere on the Delayed Fracture of Glass.** GURNEY, G. and PEARSON, S. *Proc. phys. Soc. Lond.*, 1949, **62B**, 469. Experiments show that water vapour and carbon dioxide both cause delayed fracture in glass (rods) in bending under constant load. 14 refs.

309. **Strength of Plastics and Glass.** HAWARD, R. N. 1949, Cleaver Hume Press, London; Interscience Publications, New York. The mechanism of fracture and the influence of cracks are discussed. For long abstract *see under* Mechanism of Fracture.

310. **Experimental Studies on Form and Growth of Cracks in Glass Plate** (in English). HIRATA, M. *Report, Inst. of Chemical and Physical Research, Tokyo*, 1931, **16**, 172–95.

(1) Cracks produced by linear temperature gradient. (2) Central heating by flame. (3) Cracks produced by bending. Profusely illustrated.

311. **A Study of the Influence of Temperature on the Mechanical Strength of Glass.** PROFESSOR G. O. JONES, Queen Mary College, London. Thesis for Ph.D. University of Sheffield, 1941. The thesis includes a long review of the papers by eighteen authors, 1859 to date, on the phenomena and theories of fracture of glass. Features among these papers which may have a bearing on crushing phenomena in general are as follows. (1) Lack of consistency in the results of breaking tests of glass plates and wide divergencies in results for pure materials, e.g. rock salt. Values for polycrystalline materials are much less divergent. (2) The strength of plate glass is doubled when time of loading is reduced from hours to seconds. A reversal of this effect occurs at temperatures above 150°C. Glass which had been loaded for a long time was immediately restored to very nearly its original strength on release from the load. (3) Compressive strength can be as much as twelve times the tensile strength. With glass rods, compression cracking is regarded as failure under tension. (4) The strength of glass fibres is increased when immersed in liquid air, treated with hydrofluoric acid, by contact with sulphur dioxide while annealing, by contact with certain liquids such as paraffin oil or sodium silicate solution, by varnishing, by armour plating, and by reduction in the depth of flows. A flaw depth of at least one micron is required to cause weakness. (5) The strength after vacuum treatment is reduced by contact with certain liquids or their vapours, e.g. water, alcohol, benzene, the view being that certain liquids force open the cracks or neutralize the cohesive forces. Some of the results and conclusions are regarded by the author as of doubtful reliability. Glass fibres are not uniform in tensile strength. Even if the strengths of fine and coarse fibres prepared in the same way were found to be equal, the much lower tensile strength of massive glass still needs explanation. Orientation of bubbles during the drawing of the fibres could provide an explanation. As to the weakening of glass under prolonged stress, this could be caused by development of cracks and entry of air or other gas, which neutralizes the cohesive force across the cracks. There is no weakening in vacuum. The strength in vacuum could be made permanent by treatment with certain liquids or salts. A liquid between solid surfaces can behave in some respects like a solid.

312. **The Interpretation of Experimental Data on the Strength of Glass.** JONES, G. O. *J. Soc. Glass Tech.*, 1949, **33**, 120–37. The main conclusions of experimental work on the strength of glass are discussed from the point of view of the Griffith flaw theory and of later theories of the strength of solids. An attempt is made to present a broadly correct interpretation of the phenomena and to suggest why other explanations of particular phenomena may be incorrect. The possible origins of flaws are discussed and suggestions made as to the most useful directions for further experimentation. This paper embodies much material presented by the author in his thesis to Sheffield University in 1941. 24 refs.

313. **Behaviour of Glass under Stress.** JONES, G. O. Glass, Chap. 5, pp. 70–100. Methuen's Monographs on Physical Subjects, 1956, 113 pp. Theories concerning the mechanism of fracture of glass are summarized and discussed, particularly with regard to the significance of cracks and flaws, external and internal. The effects on the strength of glass of gases and liquids in contact, and the reasons put forward for these effects are discussed, together with the effects of other surface treatments. The chapter is a concise account of the chief experimental work and observed phenomena relating to strength and fracture.

314. **The Investigation of the Brittle Fracture of Glass with Ultrasonic Application.** KERKHOF, F. *Naturwissenschaften*, 1953, **40** (18), 478. The new method of two-dimensional investigation of fracture offers a method of measurement where no Wallner lines are evident. Illustration of interfering waves produced by breaking a glass rod, while being subjected to an ultrasonic wave of 9·1 MHz. 2 refs.

315. **The Fracture of Solids. The Fracture of Glass.** MOORE, H. *Metallurgia, Manchr.*, 1949, **39**, 179–81. Deals with the physical properties, surface character and weaknesses.

316. **Influence of Water Immersion Treatment on Tensile Strength of Glass. Effect of Temperature.** MOORTHY, V. K., TOOLEY, F. V. and STOCKDALE, G. F. *J. Amer. ceram. Soc.*, 1956, **39** (11), 395–8. Glass rods were drawn to have middle diameters of 0·009 to 0·014 in. of several types of glass and immersed for 24 hours in distilled water at temperatures 30°, 60° and 90°C before making tensile tests in comparison with dry (control) specimens. The increases in strength varied according to composition, and the times of arrival at maximum strengths varied likewise. The increases also varied according to the temperature of immersion and ranged from 7 to 36% according to the composition of the glass. Results were consistent with the view that chemical reaction may result in strength increases due to reduction in stress concentration potential at flaws. 6 refs. *See also* previous paper: Stockdale *et al.* Changes in Tensile Strength of Glass caused by Water Immersion Treatment, *J. Amer. chem. Soc.*, 1951. **34** (4), 116–21.

317. **The Properties of Glass.** MOREY, G. W. 1954, Reinhold, New York. An account in 20 chapters of the physical properties of glass, contains a great deal of experimental detail.

318. **The Fatigue of Glass under Stress.** OROWAN, E. *Nature, Lond.*, 1944, **154**, 341.

319. **The Structure of Abraded Glass Surfaces.** PRESTON, F. W. *Trans. opt. Soc., Lond.*, 1922, **23**, 141–64. The author considers that in grinding, elastic stress is first caused, then fracture occurs.

320. **Surface Strength of Glass and Other Materials.** PRESTON, F. W. *J. Soc. Glass Tech.*, 1933, **17**, 5–8. The data on fibres could be accounted for by supposing that the surface actually contributed some element of strength. Condon remarked (*Physics of the Glassy State*, University of Iowa, 1953) that the figures seemed obscure as a matter of physics, although he might agree with them.

321. **The Fracture of Glass.** PRESTON, F. W. *J. appl. Phys.*, 1942, **13**, 623.

322. **Strength of Glass and Duration of Stressing.** PRESTON, F. W. *Nature, Lond.*, 14 July 1955, **156** (3950), 55 (Correspondence). Refers to the experimental results of T. C. Baker reported in *J. appl. Phys.*, 1942, **13**, 623. Mechanical properties of Glass. In the equation $fx \log_{10}(t/6) = 65\,000$ it is better to plot reciprocal f= breaking stress in lb/sq. in. against log t= duration of steady load in microseconds. A straight line is obtained. If extrapolated at both ends, the following implications are seen: (a) the stress that can be supported for an infinitely long time is zero. (b) At very short time, no finite stress is sufficient to break, if the duration is less than 6 microseconds. The implication of (b) is not clear. Presumably the curve cannot be extrapolated too far or perhaps the finite velocity of sound or of crack propagation comes in.

323. **The Shoe on the Other Foot.** PRESTON, F. W. *Bull. Amer. ceram. Soc.*, 1954 (12), 355–8. The paper in dealing with the characteristics of glass fibres and anomalous tensile strength results, points out the necessity of ensuring that the correct questions are asked before investigating anomalies. The breaking strength of 1 and 40 thousandth in. diam. fibres were 491 000 and 117 000 lb/sq. in. respectively. After seeking for explanations among various workers, flaw theories, etc., it was found that if the fibres were prepared under identical conditions, e.g. temp. and time of drawing, so as to avoid variations due to 'forming conditions', the tensile strengths did not vary with diameter. It had been found possible to produce fibres of up to 700 000 lb/sq. in. tensile strength and of small variation. 13 refs.

324. **A Note on the Velocity of Crack Propagation in Glass.** RAWSON, H. *J. Soc. Glass Tech.*, 1952, **36** (12), 297–9. A review of previous work.

325. **Experimental Study of Fracture of Glass. I. The Fracture Process.** SHAND, E. B. *J. Amer. ceram. Soc.*, 1954, 37 (2), 52–60. A concept of fracture is developed from experimental data. Fractures are found to originate at flaws or cracks of finite size, most of which are at the surface. The mechanism is one of crack propagation which begins when the local stress at the crack exceeds a minimum value. The rate of propagation increases with crack growth until a critical stress is reached at the crack tip which coincides with a limiting crack velocity. This limiting condition is identified with the boundary of the mirror surface of the fracture. From calculations to be presented in Pt. II, the critical stress is estimated to be several million pounds per square inch. Shand quotes Littleton as having made glass rods of great strength by protecting the surface. He had decided that whatever was wrong was at the surface. (Ref. S. N. Zhurkov, Increased Strength of thin filaments, *J. tech. Phys., Moscow* (*Zh. tekh. Fiy.*), 1935, 1, 386–99.)

326. **Experimental Study of Fracture of Glass. II. Experimental Data in Support of the Concept Put Forward in Pt. I.** SHAND, E. B. *J. Amer. ceram. Soc.*, 1954, 37 (12), 550–72. (1) Effect of temporary overstresses. Data shown that such stresses may weaken glass permanently, and that this effect results from slow propagation of fracture flaws. Early rates of crack propagation are determined, at orders of 5×10^{-6} ft/sec. (2) Fracture velocities during later development of process. The velocity is not necessarily uniform, but is governed individually by such factors as degree of load relaxation occurring during the dynamic phase of the process. (3) Evaluation of critical stress. Methods of stress analysis are developed from experimental data. Three sets of data are found to give consistent values for a factor proportional to critical stress, which is roughly evaluated at 2·5 to 5·0 million lb/sq. in. (for the glass used). 20 refs. The works of A. Smekel, published in 1936, A. A. Griffith, 1920–4, and of Orowan and Poncelet, are quoted.

327. **Strength of Glass.** SLAYTER, G. *Bull. Amer. ceram. Soc.*, Aug. 1952, 276–8. Reasons for the high strength of glass fibres are put forward. They refer mainly to the method of preparation. A series of photographs shows the structure at the fracture edges of glass flakes and on the surface of glass fibres.

328. **Dependence of Ultimate Strength of Glass under Constant Load, on Temperature, Ambient Atmosphere and Time.** STUART, D. A. and ANDERSON, O. L. *J. Amer. ceram. Soc.*, 1953, 36 (12), 416–24. An equation is derived relating the strength of glass to surface conditions, temperature and ambient atmosphere. The equation predicts a static fatigue limit, the magnitude depending on these conditions. It also predicts that for large stress and short breaking times, the breaking strength should vary directly with the inverse logarithm of breaking time. 13 refs.

329. **The Surface of a Glass Fracture in the Electron Microscope.** TERAO, NOBUZO and SHIGEFUMI, OKADA. *Glass Ind.*, 1953, 34 (2), 71–2. Shows that small round bodies appearing in the polished area around the origin of a fracture are possibly sub-fractures formed parallel to the principle fracture surface when glass ruptures suddenly. Micrographs. 8 refs. Translation from French by F. W. Preston.

330. **History of the Strength of Materials.** TIMOSHENKO, S. P. 1953, McGraw-Hill Publishing Co., New York. 439 pp. Chap. 12, 358–62. This section deals with the strength of glass. For abstract, *see under* Mechanism of Fracture.

331. **Effect of Preparation Condition on Tensile Strength of Soda Lime Glass Rods.** TOOLEY, F. V. and STOCKDALE, G. F. *J. Amer. ceram. Soc.*, 1952, 35 (4), 83–5.

QUARTZ: SURFACE PROPERTIES

332. **The Effect of Prolonged Grinding on the Density of Quartz.** DALE, A. J. *Trans. Brit. ceram. Soc.*, 1923–4, 23, 211–6.

333. **The Surface of Finely Ground Silica.** DEMPSTER, P. B. and RITCHIE, P. D. *Nature, Lond.*, 29 Mar. 1952 (4300), 538–9; *J. appl. Chem.*, Apr. 1953, 182–92. A vitreous soluble layer on quartz particles is produced by surface flow during grinding. The soluble layer is not discrete but merges into the less soluble core. The density of quartz is reduced on grinding.

334. **Physico-Chemical Studies on Dusts. 6. Electron Optical Examination of Finely Ground Silica.** GIBB, J. G., RITCHIE, P. D. and SHARP, J. W. *J. appl. Chem.*, May 1953, 213–8. Changes in surface structure brought about by removal of the high solubility layer from crystalline quartz and fused silica dusts by 40% HF are studied by electron optical methods. The changes in pattern show that the original surface layer is amorphous (estimated thickness 0·03–0·06 microns). There is also evidence of a layer of minute crystallites. The experiments were done on materials ground for many hours from a 70–90 mesh powder, the final size being approximately from 1 to 5 microns.

335. **Crushing and Grinding Studies in Quartz.** GROSS, J. and ZIMMERLEY, S. R. *Rep. Invest. U.S. Bur. Min.*, No. 2880, 1928. *See* Fundamental Aspects, General Papers.

336. **Heat of Crystallization of Quartz.** RAY, R. CHANDRA. *Proc. roy. Soc. A*, 1922, **101**, 509–16. By solution of sand and of crushed vitreous silica, the author found that vitreous silica has a greater heat of solution than crystalline silica by 6·95 kg/cal. He also found that in 18 hours' grinding 31% of the crystalline material had become vitrified.

337. **The Effect of Long Grinding on Quartz. (Silver Sand.)** RAY, R. CHANDRA. *Proc. roy. Soc. A*, 1923, **102**, 640–2. It was found that when silver sand is ground for a long time the density becomes lowered, the fall showing that as much as 25·7% of the crystalline material has become vitrified. The densities found are as follows: Unground sand—2·638; sand ground for 15 h—2·528, crushed vitreous quartz—2·208. The value for the vitrified part agrees fairly well with that found from the data of the molecular heats of solution.

338. **The Amorphous Surface Layer on Finely Ground Crystalline Quartz.** SAYRE, J. G. and MICHENER, J. W. *Bull. Amer. ceram. Soc.*, 1956, **35** (4), 27. The thickness of the amorphous (Beilby) layer was investigated with the diffraction stage of the electron microscope. Diffraction patterns of fine quartz particles show thickness of amorphous layer to be 500 to 1000 Ångström units. There is no apparent boundary between crystalline and amorphous area. The layer is thinner for other crystalline particles examined.

339. **Comparative Crushing Experiments with Crystalline and Vitreous Quartz.** WOLF, K., HENNICKE, H. and SMEKAL, A. *Verfahrenstechnik*, 1939 (4), 115–7. The anisotropic nature appears to have no recognizable effect on the size distribution and form of the crushed product. A large number of photographs demonstrates the equivalence of the two materials in their crushed product.

SIZE DISTRIBUTION

340. **German Standard for Graphic Representation of Size Distribution.** D.I.N. 4190. *See under* Kiesskalt.

341. **Particle Size and Fine Grinding.** *Sci. Libr. bibliogr. Ser.* No. 560, 1941. A selection of the more theoretical treatments. 1924 to date. 40 refs.

342. **Study of Ground Materials: Theoretical and Experimental Investigations on Distribution of Different Grain-sizes in Ground Products.** ANDREASEN, A. H. M. *Kolloidchem. Beih*, 1928, **27**, 349. Shows that increase in surface area per unit weight is generally not sufficient indication of the grinding, while the distribution of the particles is; the frequency curve follows Martin's compound-interest law; no general law exists

governing the distribution of grain sizes, as this distribution varies with the manner of grinding and with the material; and the compound-interest law does not hold for ball mill products. Discussion.

343. **Methods of Representing Distribution of Particle Size.** AUSTIN, J. B. *Industr. Engng Chem.* (*Anal.*), 1939, **11**, 334–9.

344. **Relation Between the Gauss Normal Distribution and the Distribution Function of Rosin, Rammler and Sperling.** BATEL, W. *Chem.-Ing.-Tech.*, 1954, **26** (2), 72–4. In practice, particle distribution is generally represented with help of R.R.S. equation, as a double logarithmic function of the particle system. This function is regarded as applying to a 'Normal' distribution. This widens the scope of application of the R.R.S. equation and can lead to many speculative interpretations.

345. **Possibilities of Errors in the Estimation of Particle Size Distribution.** BATEL, W. *Chem.-Ing.-Tech.*, 1956, **28**, 81. In the manipulation, such as sampling, dividing, sieving, evaluating and presenting results, necessary for determining the size distribution of say a heap of granular material, errors can occur such as demixing, agglomeration, etc. An attempt is made by the author to state the sources of error and to suggest measures for their avoidance.

346. **Studies in Particle Size Distribution (Determination).** BERG, S. *IngenVidensk. Skr. B.* (*Copenhagen*), 1940, (2).

347. **Determination of Grain Size Classification of a Crystalline Powder by X-Ray Diffraction.** BERNARD, R. and RIVIERE, R. *C.R. Acad. Sci., Paris*, 8 Feb. 1954, **238** (6), 666–9. Although not of such wide application X-ray diffraction enables the characteristics of crystalline powders to be obtained without too much difficulty. It confirms the presence in ball milled powders, of two modes of dispersion quite distinct. These are (1) the dispersion produced by impact and (2) the dispersion, very fine, produced by attrition. 5 refs.

348. **A Review of the Present Position of Particle Size Distribution.** BIERBRAUER, E. and HOENIG, F. *Zement*, 1935, **24**, 285–90, 301–5. (1) Technical significance. (2) Graphic representation of sieve analyses. (3) The advantage of logarithmic presentation. Graphic interpretation of surface area. Mathematical analysis of particle shape factors. Criteria of particle fineness.

349. **Law Governing the Connection between the Number of Particles and their Diameters in Grinding Crushed Sands.** BLYTH, C. E., MARTIN, G. and TONGUE, H. *Nature, Lond.*, 1923, **111**, 842. Law relating to continuity of particle size in fine grinding. In every case tested it has been found that $N=ae^{-bx}$. It is therefore possible to calculate the number of particles of any given diameter without sieving. N=No. of particles of diameter x; N and x are variables; a and b are two constants, characteristic of the samples tested. In other words: the rate of increase, with decrease of diameter, of the number of particles present of any given size is proportional to the number of particles of that size. It becomes possible to calculate exactly the theoretical amount of work required to produce powders of different degrees of fineness.

350. **Crushing and Grinding Characteristics as Determined from Screen Analyses.** BOND, F. C. and MAXSON, W. L. *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1934, **112**, 146–60. Gaudin, *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1926, **23**, 253. It is shown that if log per cent retained on a screen and passing the next higher screen in the Tyler scale against log screen aperture, the curve for the finer sizes of a homogeneous crusher or mill product would be a straight line. In the present work, ordinal numbers are assigned to the Tyler standard scale. The log/log plot is a straight line as in Gaudin's work right down to colloid size range. If the material is not homogeneous, there will be variations. The slope of the curve depends on character of ore and conditions. An increase in slope shows a decrease in power lost in overgrinding. The presence of a hard grinding fraction and suitability of grinding conditions can be shown. Equations are given for

computing surface area and percentage of unground fines. Examples are calculated. Six requirements as items of information are stated, and the importance of knowing the size distribution is stressed. They are (1) size distribution, (2) presence of a hard grinding fraction, (3) location of natural grain sizes, (4) presence of different materials, (5) amount of very fine material present, (6) surface area.

351. **Control of Particle Shape and Size.** BOND, F. C. *Chem. Engng*, 1954, **61** (8), 195–8. The shape factor is discussed and a means by sieving is given for finding dimensions B and C, the dimension A (length) not being assessable by screen analysis. The relation of work input to particle size is discussed, and the Gates–Gaudin–Schumann distribution represented by the equation: $y=100(x/K)^m=80(ex/p)^m$, where y = per cent passing any size x, K is the size 100% passes and m is the slope of the plotted line. The fundamental size distribution law of crushed and ground products was apparently first discovered by Gates, *Trans. Amer. Inst. min. (metall.) Engrs*, 1915, **52**, 875. The size distribution line for work equivalent product has a slope of 0·5. Using Bond's theory, each regular size fraction of a homogeneous product represents an equal amount of work. 5 refs.

352. **The Graphic Representation of the Size Distribution of Fly Ash.** BRAUKMANN, B. *TonindustrZtg*, 1954, **78** (13/14), 213; Verein Deutsche Ingenieur Tagung, Staubtechnik, Bad Kissingen, 1954. The results obtained by two methods, sedimentation and air elutriation, are compared and discussed. The available results do not yet give clear and reliable indications of size distribution, and a collaborative effort is proposed for revising the methods with a view to clarifying certain gaps in the field.

353. **The Kinetics of Grinding Processes.** BRENNER, R. and VIDMAJER, A. *Kolloidzschr.*, 1955, **143** (3), 154–61. On the assumption of continuous grain size distribution, general equations for residue of grinding processes of first and second order are established and their general mathematical significance is discussed. Theimer's equation giving purely exponential time dependence of residues is verified or extended and made more precise. Grinding processes with more general log time dependence of residues can be interpreted as second order processes. Rosin–Rammler grinding without sintering, however, is of first order type, for it is shown that for pure comminution, the dispersion parameter must be independent of the time of grinding. 3 refs.

354. **The Rosin-Rammler Size Distribution in Ground Powders.** BRENNER, R. and VIDMAJER, A. *Metall*, May 1955, **9** (9/10), 395–403. In powder metallurgy, it is important to know all the powder characteristics in relation to methods of preparation, not only from the more obvious point of view of the quality of the finished article, but from that of manipulation during the pressing or extrusion processes in making the finished article. It is shown mathematically and graphically how the Rosin-Rammler formulae can represent the varying size distributions of powders and can emphasize the salient features of the distribution. The effects of particle shape on the results are discussed. Applications of the formulae during the grinding process can serve to indicate whether the process is one of simple grinding, or whether aggregation is occurring. The R.R. formula is empirical and cannot be derived from an elementary fracture law. 8 refs.

355. **Generalized Law of Size Distribution.** BROWN, R. L. *J. Inst. Fuel*, 1941, **14**, 129. The product of ideal repeated fracture is a combination of products of simple fracture each of which follows the Ideal Law. The size distribution is therefore a sum of exponential terms, which are shown in the present paper to be approximated with remarkable accuracy by the Rosin-Rammler relation. In this approximation, the distribution constant, n, is almost independent of the reduction ratio of the breakage, so that n may be used as a measure of the number of complete cycles of breakage that a broken product has undergone.

356. **Matrix Analysis of Machines for Breaking Coal.** CALLCOTT, T. G. and BROADBENT, S. R. *Brit. Coal Util. Res. Ass. Document* C/4945, 1955. *See* Nos. 32 and 36.

357. **Application of the Logarithmic Normal Law of Distribution to the Calculation of the Granulometric Characteristics of Comminuted Materials.** CHERNYI, L. M. *C.R. Acad. Sci. U.R.S.S.* (*Dokl. Akad. Nauk S.S.S.R.*), 1950, 72, 929–32; Abstract in *Chem. Abstr.*, 1951, 45 (6), 2287i. It is known that the dimensions of the particles of the original material largely determine the granulometric characteristics of the comminuted material. Here the logarithmic normal law of distribution with variable magnitude of dispersion is stated and examined. From the known constants of the granulometric curve, the total yield for any particle dimension may be calculated. A table is given showing analyses for various rocks and granulometric characteristics calculated by different formulae. The method giving the most exact results is that with variable magnitude of dispersion, based on the logarithmic normal law of distribution of particles during pulverization.

358. **Fitting Bimodal Particle Size Distribution Curves.** DALLAVALLE, J. M., ORR, C. and BLOCKER, H. G. *Industr. Engng Chem.* (*Industr.*), 1951, 43, 1377–9. Mathematical procedures for describing bimodal size distributions are considered.

359. **Mathematical Description of Certain Breakage Mechanisms.** EPSTEIN, B. *J. Franklin Inst.*, 1947, 244 (12), 471–7. The observation that particle size distributions obtained from some breakage processes (e.g. relating to coal) appear to be logarithmico-normal has been examined, and in an attempt to find an explanation the author has constructed a statistical model, which he discusses.

360. **Statistical Aspects of Fracture Problems.** EPSTEIN, B. *J. appl. Phys.*, 1948, 19, 140–7. For crushing and grinding operations particle size distributions have a marked tendency for log size to be normally distributed.

361. **Logarithmico-Normal Distribution in Breakage of Solids.** EPSTEIN, B. *Industr. Engng Chem.* (*Industr.*), 1948, 40 (12), 2289. A statistical model is constructed for breakage mechanisms and a breakage process is conceived of as depending on two basic functions, a probability of breakage function and a weight distribution function, which are considered. The distribution function $Fn(x)$ after n steps in the breakage process is asymptotically logarithmico-normal, a form of distribution frequently observed.

362. **Particle Size Distribution of Products Ground in a Tube Mill.** FAGERHOLT, G. G.E.C. Gads Forlag Copenhagen, 1945. 217 pp. 65 refs. Translated into English by E. Christensen. The author has undertaken a critical analysis of the formulas proposed which are intended to represent size distribution of ground products. In order to test whether experimental data follow a certain law it is necessary that the error of the experimental method should be known. Since the literature has little to say concerning the error of fineness analysis, it has been necessary to undertake a statistical investigation of the errors involved in sieve and sedimentation analyses. The errors in sampling and in counting were also investigated. The grinding experiments with a ball mill are described and the size distribution of the monodisperse and polydisperse materials and other solids ground for various periods are presented in tabular form and used to test the formulae of Martin, Heywood, Weinig, Rosin and Rammler, Gaudin, Raller, Hatch and Choate. It was found that none of these formulae possess the validity claimed or universal validity for the size distribution of a ball mill product, and neither has the more general formula, of which these individual formulae may be regarded as special cases. A more extensive investigation of the particle size distribution is made with the aid of the transformation method, an account being given of Kapteyn's theory for the occurrence of skew distributions in the growth process. Formally, one can hardly regard size distribution as the result of a growth process; hence it is probably impossible from the transformation function to draw conclusions with respect to the grinding process itself, but owing to its simplicity, the method is of great advantage in the mathematical treatment of the present problem. The author, after numerous attempts, did not find it possible to prove or disprove Rittinger's theory. Since it is impossible

to determine how large a proportion of the energy input to a tube mill is of benefit to the actual grinding process, it is in principle impossible to test the validity of Rittinger's theory with tube mill experiments. He also points out the doubtful value of testing surface area by means of solution of quartz in hydrofluoric acid as used by Gross and Zimmerley and Martin. He criticizes the validity of Andreasen's finding that surface does not increase in proportion to time of grinding and presents a detailed treatment of the variation of parameters with time of grinding.

363. **Dust Technique. I. Graphs, Equations, Characteristic Quotient.** FEIFEL, E. *Radex Rdsch*, 1952 (6), 235–54. If the results of a dust analysis are to compensate for the work and expense of obtaining them, the proper selection and application of the method must be supplemented by adequate representation and interpretation. A few distribution curves of dusts are presented in the conventional manner and the advantages and drawbacks of graphs with varying co-ordinate scales are discussed. As many particle distributions can be described satisfactorily, though only approximately, by an exponential equation, it is possible to find adequate expressions descriptive of dusts. The subject is treated almost entirely mathematically. 9 refs. To characterize a dust the author proposes the term 'Kennbruch', which is a 'characteristic quotient', and is the quotient of the X axis values corresponding to residues $100/e$ and $100/\frac{1}{2}e$ respectively.

364. **Dust Technique. II. Medium Size Particles.** FEIFEL, E. *Radex Rdsch.*, 1953 (6), 8–26. For dedusting technique, a variation from the normal statistical approach to particle size distribution is desirable, especially with regard to interpretation of 'mean values'. A mathematical and graphical treatment of the subject is presented. 15 refs.

365. **Dust Technique. III. Fine and Superfine Particles.** FEIFEL, E. *Radex Rdsch.*, 1954 (7/8), 239–55. Stress is laid on the importance of size and number rather than on weight, when considering matters of hygiene or disease. The harmful and harmless sizes are discussed, and investigation is made into the size distribution of sub-microscopic particles down to less than 1 mu. It is suggested that in a normal distribution of particles, a deficiency occurs due to the resistance to separation as particles become smaller. This may explain the deficiency where solid particles are concerned, but can hardly do so where atomized liquid solutions (NaCl) are concerned, for the results from this and from analyses of dry rock drilling dust both follow the well known exponential law in a satisfactory manner. The lack of sufficient data from micron and sub-micron sizes is discussed.

366. **Presentation and Interpretation of Size Distribution.** FEIFEL, E. *Radex Rdsch.*, 1954 (7/8), 237. Criticism by H. zur Strassen, *ibid.*, 1955, (1), 345–8. *See under* Strassen.

367. **Investigations into the Performance of Crushing and Grinding Apparatus.** FERET, R. *Baumaterialienkunde*, 1904, 9 (11/12), 161–85. The paper is mainly concerned with the size distribution of various products and concludes that the smaller the product the nearer the approach to a generally applicable law of size distribution.

368. **Grading Aggregates. 1. Mathematical Relations for Beds of Broken Solids of Maximum Density.** FURNAS, C. C. *Industr. Engng Chem.* (*Industr.*), 1931, 23, 1952–88.

369. **An Investigation into Crushing Phenomena.** GAUDIN, A. M. *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1926, 73, 253–313; *Quarry*, 1926, 31, 289. The information concerning comminution is condensed into several rules which would be of use in developing a systematic theory. Eight rules are given. For homogeneous materials the percentage weight of grains of various sizes and the sizes themselves follow a definite law. Distribution curves are presented for products from various crushers, 79 curves in all. Varying conditions in feed and milling are represented. He concludes that when a logarithmic size curve of a crushed product from a sized feed is not a straight line, the rock is heterogeneous in character, i.e. under conditions that yield a straight line for quartz. A hump in a curve indicates a preferential breakage action. Quartz and limestone were used for the majority of the experiments. The expression for the straight

line portion of the curve makes it possible to determine values for −200 mesh. The steeper the line the less the amount of fines. Surface calculations vary greatly with the slope of the line. Theoretical efficiency figures based on surface energy values range from 6 to 25%.

370. **Principles of Comminution—Size and Surface Distribution.** Gaudin, A. M. and Hukki, R. T. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 67; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1779. Previous results are correlated with new experimental data obtained with a special single-impact pendulum crusher and a system of gas absorption for surface measurement. It is shown that size distribution in a crushed solid is represented very closely by a straight line on a log size versus log % undersize plot. Divergence from the straight line occurs with the larger particles, and reasons for this are suggested. It is argued from these relationships that surfaces in each of a series of size ranges of fixed ratio are equal, and this equality of surface is demonstrated experimentally.

371. **A Theory of the Size Distribution of Particles in a Comminuted System.** Griffith L. *Canad. J. Res.*, June 1943, A. **21**, 57–64; *Sci. Abstr. A*, 1943, **46**, 202. It is shown that the problem of size distribution of particles in a system that has been ground can be treated by the general methods of the theory of probability. The mathematical procedure is identical with that used in statistical mechanics of gases, although the fundamental ideas are different, as the molecules of a solid are not free to move. The distribution laws agree with empirical laws for particles of sizes down to 1 mu, but proof of the theory will depend upon study of size distribution in colloidal systems.

372. **Grinding Functions and the Kinetics of Crushing Processes.** Huttig, G. F. and Moser, F. *Planseeberichte fur Pulver metallurgie*, June 1954, 2 (1), 15–9. Review of literature covering throughput characteristics, frequency of grain size distribution, rate of grinding and rate of change of grain size distribution. 11 refs.

373. **The Derivation of Specific Surface from Particle Size Distribution.** Kiesskalt, S. and Matz, G. *Z. Ver. dtsch Ing.*, 21 Jan. 1951, **93** (3), 58–60; Summary in *TonindustrZtg*, 1951, 92. The authors have re-evaluated the Rammler surface area formula with modifications based on Heywood's form factors. They have shown how specific surface area can be derived from the Rosin–Rammler–Bennett distribution graph and have tabulated the calculated idealized values based on n and d', for use in calculating the actual surface from the equation: $O = f/s . O_{k \cdot i}$., where $O_{k \cdot i}$. is the idealized surface shown in the table, f is the shape factor and s is the specific gravity. 5 refs.

374. **New Insight into Particle Size Distribution Graphs and Surface Tables.** Kiesskalt, S. *Z. Ver. dtsch. Ing.*, 11 Dec. 1952, **94** (35), 1137–40. Since the normal presentation of size distribution does not give an adequate representation of the powder characteristics, greater reliance is placed on the Rosin-Rammler curves, which also serve for the calculation of specific surface, knowledge which is of equal importance with that of size distribution. The presentation of size distributions by the Rosin–Rammler–Sperling straight lines in a double logarithmic graph has been extended to include special distributions (one size missing, one size predominant, classified distributions), for which lines deviating from the straight are obtained. The application of these new curves to size distributions obtained in various grinders or pulverizers is discussed. Nine references to the Works of Kiesskalt, Weidenhammer, Hanssen, Anselm, Honig, Davies, Smekal, Puffe.

375. **The New German Standard for the Graphic Representation of Size Distributions.** Kiesskalt, S. International Congress on Ore Dressing, Goslar, May 1955. Gesellschaft Deutscher Metallhutten und Bergleute/Clausthal-Zellerfeld. The author discusses the Rosin Rammler Sperling Bennett presentation of size distribution, the system now being incorporated in D.I.N. 4190. The method of calculating the surface area from the

R.R. line is described and shown graphically, $O_k d'$ having been previously calculated and shown in correspondence with the n values. O is then calculated by $O = f/s . O'_k$ (Puffe), where f is the Heywood form factor and s is the specific gravity. Certain anomalies and problems, such as one size missing or increased are discussed and it is shown how the evaluation by the method given is subject to much less inaccuracy than the sampling and sieving data themselves. Deviations from mean values of specific surface are calculated. They increase sharply with increasing d' and decreasing n, and can reach 30% for a normal range of n and d'. In the English summary of this paper, the author states that about 80% of mechanically disintegrated products of all kinds can be represented by R.R.S. lines, and the surface areas can be shown on further peripheral scales, as shown in the main paper. The restriction of surface determinations to R.R. *straight* lines by this means has led to suggestions, mostly complicated mathematically, for deriving the surface from 'off-size' gradings. Weidenhammer, Stange, Langemann are quoted. The author has tried to evaluate such curves by considering respective portions of such curves and working in small ranges. This is easily done by introducing a ladder scale into the system of co-ordinates. Feifel has also considered other means. The smallest value of n hitherto obtained is 0·4. It can be said that the value of n for one and the same material is not changed by machine treatment. Rammler made use of this fact to investigate whether the fineness of grinding of coal mills could be predetermined, or whether large deviations can be arranged. He also shows that n must lie within a certain band and that specifications outside this band can not be met. The system of co-ordinates thus proves to offer great possibilities; its further use is likely to be greatly extended because the progress here referred to has only been made during the last 2 or 3 years. The paper presents a review of recent work. 1 graph, 15 refs. *See also Z. Erzbergb. Metallhüttenw.* 1955, **8**, 637, and *Staub*, 1956 (46), 515–6.

376. **How You Can Predict Product Screen Analyses.** KLOVERS, E. J. *Engng Min. J.*, June 1949, **150**, 80–1. Shows how estimated screen analyses of the products to be expected from a given crusher or grinding mill can be made with considerable accuracy when a screen analysis of the same material is available at a size not too far removed from that of the desired product. The graphical method is illustrated.

377. **Observations on the Co-ordinate System of Rosin and Rammler.** KNESCHKE, A. Bergakademie (Freiburg-i-Sachsen), 1954, **6**, 535–41. The author has examined the relation between the concepts 'fineness', 'uniformity' and 'progress in grinding' on the basis of D.I.N. 4190 particle size distribution, and has found a functional correlation between n and d' by the introduction of the concept 'surface distribution'. The matter is not yet fully elucidated.

378. **On the Grain Size Distribution of Pulverization Processes.** KOPPE, H. *Nachr. Akad. Wiss., Göttingen*, 1946 (2), 119–22; *Sci. Abstr. A*, 1949, **52**, 876. A theoretical derivation of the formula: $n(x, t) \simeq \text{const}\, \Sigma^{-t \approx x}$ where $n(x, t)$ is the number of particles of size x after pulverization has continued for time t, and $\approx(x)$ is a function approx. varying as the mass of the particle. This result is almost independent of the method of pulverization used.

379. **The Distribution of Particle Sizes. Pts. I and II.** KOTTLER, F. *J. Franklin Inst.*, 1950, **250** (4), 339–356 (5), 419–41; 1951, **251** (6), 617–41. In this paper the older literature on distribution of particle sizes is reviewed critically. The distribution law should be connected with the law of growth of crystals, for which is chosen the exponential law as Galton indicated long ago in an analogous case. The law which then follows is the so-called Logarithmico-Normal law. In the application of that law to experimental data, graphical analysis by means of special charts is generally used. It is shown why this purely graphical method should be replaced by an algebraic one, such as is used, for instance, in psychophysics with a similar problem.

380. **Graphical Form for Applying the Rosin and Rammler Equation to Size Distribution of Broken Coal.** LANDERS, W. S. and REID, W. T. *Inform. Circ. U.S. Bur. Min.*,

No. 7346, 1946. 5 pp. Size distribution in broken coal obeys a law expressed by the Rosin–Rammler equation. Bennett's modification is the basis of a graphical representation of the sieve analysis of coals. A printed form is described, the significance of equation constants is discussed, and examples are given.

381. **Computation of the Specific Surface of Dispersoids.** LANGEMANN, H. *Chem.-Ing. Tech.*, 1955, 27, 27. An idealized specific surface of dispersoids with salient R.R.S. characteristic curves and arbitrary integration limits is calculated by means of incomplete gamma function, and the *Ei* function. Surface tables are given which make it possible to read off the idealized specific surface with practical integration boundaries. They widen the boundary scale of the product surface as applied in D.I.N. draft 4190 for these boundaries.

382. **Size Distribution in a Randomly Fractured Solid and its Application to Coal.** MANNING, A. B. *J. Inst. Fuel*, 1952, 25, 31–2. Study of the effect of grinding upon particle size distribution. The latter is not static, but varies, and leads to the Rosin–Rammler law of distribution.

383. **Researches on the Theory of Fine Grinding. Pt. 1.** MARTIN, G., BLYTH, C. E. and TONGUE, H. *Pamphl. Brit. Portl. Cem. Res. Ass.* No. 4, 1924. Increase in the number of particles per unit increase in diameter is plotted against diameter. The areas between the curve, *X* axis, and any two of the adjacent ordinates is numerically equal to the number of particles between the corresponding diameters.

384. **The Computation of the Crushing Efficiency of Tube Mills.** PEARCE, S. H. and CALDECOTT, W. A. *J. chem. Soc. S. Afr.*, 1906, 7, 72. Discusses the importance of the average size of fine material, giving results based on mean average and average from E. J. Laschinger's formula: $d=\frac{d_1-d_2}{2{\cdot}3026 \log d_1/d_2}$, where d_1 and d_2 are maximum and minimum diameters respectively.

385. **Mathematical Evaluation of Size Frequency Distribution of Particles in the Subsieve Range.** PETERSON, E. E., WALKER, P. L. and WRIGHT, C. C. *Bull. Amer. Soc. Test. Mat.*, 1952, 50 (183), 70–5; Abstract in *TonindustrZtg*, 1953, 77, 348. A method is proposed for the calculation of surface area and weight distributions from microscope size frequency measurements, wherein the necessity of assessing a mean diameter to represent the size interval has been obviated. The method permits the microscopic classification of particles into broader intervals than usually recommended, thereby reducing the time to convert particles, especially when the sample contains a wide range of sizes. In this method the size frequency data are plotted in terms of the cumulative number of particles greater than a size *x*, from which intermediate values can be interpolated, if required. Equations are set up which may be integrated between any interval limits to determine the surface area of that interval. A statistical analysis of count data for coal samples at sizes from 1 to 100 mu, indicates that reproducibility is sufficient to warrant the use of the method and formulae.

386. **Graphical Presentation and Evaluation of Sieve Analysis from the Rosin-Rammler Equation.** PUFFE, E. *Z. Erzbergb. Metallhüttenw.* 1948, (1), 97–103. A procedure is described which was developed in Germany, and which in recent years has become of increasing significance in American ore dressing. The method of evaluating the equation coefficients is presented graphically and also in relation to American Standard sieves. By drawing a line from the origin of the R.R. co-ordinates parallel to the R.R. line and extending it to a peripheral scale, already calculated for values of *n* and *d*, the reading so obtained will enable the specific surface area to be calculated from the specific gravity and shape factor.

387. **Comparison of the Size Distribution of Pulverized Materials with the Size Distribution Laws.** RAMMLER, E. *Verfahrenstechnik*, 1937, (5), 161–8. The laws of Rosin, Rammler and Sperling and Bennett's results are discussed and the upper and

lower limits of validity of the constants are determined. The exponential law is discussed for coarse crushing, natural breaking, size reduction in general and for a range of materials.

388. **Shuhmann Particle Size Equation and its Relation to the Exponential Law of Particle Size Distribution.** RAMMLER, E. *Verfahrenstechnik*, 1942, **4**, 103–8.

389. **Contribution to the Interpretation of Size Analysis by the Rosin–Rammler–Bennett Graphical Representation.** RAMMLER, E. and GLOCKNER, E. *Technik, Berl.*, 1952, 7 (9), 555–7; Abstract in *TonindustrZtg*, 1952, 77 (21/22), 373. This is an extension of Puffe's method, whereby the interpretation can be simplified, and whereby with a special paper made by Schafer's Reinpapier, Plauen, Vogtland, the specific surface can be read off.

390. **The Particle Size Analysis of Crushed Products.** RATCLIFFE, A. *Proc. Instn mech. Engrs, Lond.*, 1950, **162** (3), 378–91. An examination is made of two particle size analyses which are typical of two categories of crushed products. One example represents material reduced in a hammer mill; subjected to indiscriminate reduction, it contains a preponderance of smaller sizes, and this is characteristic also of ball mill products and the small particles in the products of jaw, gyratory, and roll crushers. The second example illustrates the influence of the sizing action which occurs in the latter machines and results in a closer grading of the coarse particle fraction. These characteristic features are illustrated by graphs, and a mathematical basis is given for Gaudin's law of particle size distribution. 6 figs.

391. **Rigorous, Simple Method of Measuring and Recording Particle Size Distribution in Dispersed Material.** RIM, H. *Trans. Amer. geophys. Un.*, June, 1952, 33 (3), 423–6.

392. **Law of Size Distribution and Statistical Description of Particulate Materials.** ROLLER, P. S. *J. Franklin Inst.*, 1937, (223), 609–33. A law of size distribution has been found which relates to the weight per cent, and from this the frequency, to size of particle for finely divided materials; only two constants are involved, which are easily found. The straight line for the relationship is called the characteristic line. Departures from straight line characteristics are discussed. The distribution law is found to hold for materials reduced by mechanical, physical or chemical means.

393. **The Size Distribution of Powdered Coal.** ROSIN, P. and RAMMLER, E. *See also under* Coal.

394. **The Laws Governing the Fineness of Powdered Coal.** ROSIN, P. and RAMMLER, E. *J. Inst. Fuel*, 1933, 7, 29–36. This is the first publication in English by Rosin and Rammler on this subject. The exponential law is developed mathematically and experimental evidence from experimental grinding in tube mills is presented in support of the distribution curve and formula $R=100e^{-bx^n}$. The application of the formula permits a great reduction in the work of fineness analysis, and also the fineness curve to be extrapolated into the range of fineness where measurements are difficult. The law makes it possible to determine the specific surface of coal dust and therefore certain quantitative aspects of combustion. Curves are shown to demonstrate the change in shape of the distribution curve with increased fineness of grinding in tube mills. 7 refs. See also *Kolloidzschr.*, 1934, **67**, 1.

395. **Particle Size Distribution of Mill Products in the Light of the Theory of Probability.** ROSIN, P. and RAMMLER, E. *Kolloidzschr.*, 1934, **67**, 16. The derivation of the size frequency curve from the residue curve is explained. The size frequency curves for coarsely crushed products are divided into two component curves, each of which may be represented by one of Pearson's standard forms of equation, which can only be used to represent curves of extreme negative asymmetry which have no mode in the measurability region of particle size.

396. **Laws of Grinding.** ROSIN, P. and RAMMLER, E. *Ber. dtsch. keram. Ges.*, 1934, **15**, 399–415. The grain size distribution is best defined by the weight characteristic,

i.e. the curve showing the residue (R) or throughs (D) as a function of grain size (X), at which (R) and (D) are determined. The following law is derived: $R=100e^{-bx^n}$, where e is the base of natural logs, b and n are constants. The law proved applicable to amorphous materials and to crystalline materials irrespective of hardness or specific gravity. It could not be satisfactorily applied to materials such as ordinary ground bricks, but is generally applicable to practically all fine grinding below 1 mm. The authors attribute the first basic work on size analysis to Martin, Blyth and Tongue, *Trans. Ceram. Soc.*, 1924, **23**, 61, and quote Andreasen's work (published 1930) as giving the most accurate and reliable information on the products of crushing flint, quartz sand, felspar, barytes, iron ore in laboratory ball mills. The authors' formula is shown to be closely applicable to each of these products, in a series of graphs.

397. **Application of Rosin–Rammler Law to the 'Missing Sizes' in Screened Coal.** Scott, G. S. *Rep. Invest. U.S. Bur. Min.*, No. 3732, 1943. 9 pp. The author presents an analytical and graphical method for applying the Rosin–Rammler law to the special case where the size characteristics obtained on one screen are recalculated to show the results that would be obtained on any other screen.

398. **Contribution to the Theory of Ball Milling.** Sedlatschek, K. and Bass, L. *Powder Metall. Bull.*, 1953, **6** (5), 148–53. The shortcomings of the Rosin–Rammler formula $R/100=\exp.\left\{-(x/F)^n\right\}$ are discussed and a mathematical theory of milling processes (e.g. in ball mills) is suggested which fulfils the following conditions: (1) empirical elements are eliminated and limits of applicability can be stated *a priori*; (2) the weight percentages of the fractions are considered as a function of the milling time; (3) the initial particle size distribution is taken into consideration.

399. **Principles of Comminution. 1. Size Distribution and Surface Calculations.** Schumann, R. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1189, 1940. The cumulative size distribution equation developed by Schumann is $y=100(x/k)^m$. y is the cumulative per cent by weight finer than size x; k and m are parameters of the same significance as the corresponding terms in the Rosin–Rammler equation in the form used by Bennett and by Geer and Yancey. An example shows how this equation fits the product of a jaw crusher test for sizes down to the limit of the sedimentation balance. Calculations show that 80% of the total new surface in this product was on particles finer than 35 mesh (about 1/25 of the jaw crusher setting), the latter being only 12% by weight of the total product. 13 refs, graphs. *See under* Jaw Crushers.

400. **The Laws of Size Distribution in Crushing Processes.** Stange, K. *Ingen.-Arch.*, 1953, **21** (5/6), 368–80. A translation may be consulted at D.S.I.R. Ref. Records Section, 22964. Equations are derived for calculating the distribution and specific surface of particles formed during crushing processes. In this mathematical paper, two types of reduction processes are studied: (1) that corresponding to a prolonged grinding process in which each particle is split into two in a random manner; (2) where the particle is subjected only once to a blow which breaks it into several pieces. A simple dimensionless index is obtained to express the degree of pulverization. The specific surface attained is also discussed. The particle size distribution produced can for most purposes be represented by the Rosin–Rammler–Sperling formula (1937–40), $R=e_a^{-x^n}$.

401. **The Presentation and Interpretation of Particle Size Distribution.** Strassen, H. *Radex Rdsch.*, 1955, (1), 345–8. A criticism of the article on the same subject by E. Feifel, *ibid.*, 1954, p. 237. The criticism does not concern the analytical presentation of the size distribution laws nor the Gaussian probability distribution. Table 6 gives a summary of the data relating to the critical points of the characteristic curves in linear and logarithmic presentations. A comparison leaves no doubt that both the well known statistical distribution laws can only be presented correctly by the logarithmic function; the discussion of the formulae and of the surface distribution function $dR/da=f(\ln a)$ in a former paper should be referred to. The proposal by Bierbrauer and Honig, 1935,

to use only the logarithmic presentation for size, should not cause confusion but should aid in simplification and clarification of the relations. It should also serve for the description of dusts, which largely comply with the size distribution laws. The frequent, although not universal, use of the linear presentation, does not invalidate the arguments. Habitual practice is not necessarily correct.

402. **A New Formula for Particle Size Distribution of Products Produced by Comminution.** SVENSSON, J. *Trans. Royal Institute of Technology, Stockholm.* 1955, (88), 53 pp. (In English.) Presents a general distribution function comprising formulae of Gaudin, and Rosin and Rammler, which are regarded as special cases. The new formula is applicable to many distributions but not to those obtained by comminution of loose grained materials or products from fixed discharge openings. The chief practical application of the new formula is in test sieve calibration. An extensive table is presented to facilitate use of formula. 22 illustrations, 3 tables, 3 refs.

403. **Size Distribution.** TAGGART, A. F. *Handbook of Mineral Dressing,* 1950, Wiley & Sons, New York. Sect. 19, 145–50. 12 types of co-ordinate systems are presented, all of which are designed to straighten size distribution curves. The distribution functions of various workers are discussed and compared by data in tabular presentation.

404. **Particle Size Distribution and Mechanism of Size Reduction.** TANAKA, T. *Chemical Engineering, Japan,* 1955, **19**, 152–7; *Chem. Abstr.*, 1955, **49**, 8575. An empirical equation for determining specific surfaces, *S*, of ceramic materials is presented, using the constants in the Rosin–Rammler function. It is concluded from investigation that the exponential law is not of general application and a more general but rather qualitative distribution law is proposed. The formula presented is $S=3{\cdot}15b^{0{\cdot}82}10^{{\cdot}4-2{\cdot}15n}$, where b and n are the R.R. law coefficients.

405. **The Size Distribution of Broken Solids.** TAYLOR, J. *J. Inst. Fuel,* 1953, **26** (9), 133–8. The product of the simple crushing of solid particles can be separated into two parts: (1) residue, which has a Gaussian distribution, and (2) complement, which tends to have a Gaudin type distribution, although the simple Gaudin type distribution is only realized for solids with a non-granular structure. Values have been determined for the distribution characteristics of a number of different solids: fireclay, dolomite iron ore, magnetite, quartz and coke, and the effect of size before crushing and of the reduction ratio is studied. The application of the results is discussed in relation to (a) production of closely graded materials, and (b) to a product of maximum packing density. It is not easy by crushing alone, i.e. without screening and remixing, to obtain a high packing density. This may explain the continued popularity of the solid bottom pan mill in the refractory industry, despite its inefficiency otherwise.

406. **The Fine Crushing of Coal and Coke.** TAYLOR, J. *J. Inst. Fuel,* 1954, **27** (5), 249–54. The application of known size distribution expressions to the products of crushing operations is examined. A distinction is made between coarse crushing where *residue* and *complement* are both produced, and fine crushing where product is all *complement*. Only homogeneous materials such as glass, coal, clay, can be expected to break down to a simple grading, and then only in fine crushing operations. Porous or granular substances give products with complicated distributions. The conditions of breakdown are considered, particularly with reference to coal and coke, and the conditions are then related to the degree of dispersion of the crushed product, which in turn is the most important factor in packing density.

407. **Fundamental Laws of Grinding.** TODES, O. M. and YUROVSKII, A. Z. *C.R. Acad. Sci. U.R.S.S.* (*Dokl. Akad. Nauk, S.S.S.R.*), 1951, **77** (3), 407–9. A statistical analysis of ore dressing with graphical representation of particle size. 5 refs.

408. **The Classification Effect as Exhibited by the Rosin–Rammler–Bennett Graphs.** TRAWINSKI, H. *Z. Erzbergb. Metallhüttenw,* 1955, **8** (4), 162–70. International Congress

on Ore Dressing, Goslar, May 1955. The distribution line for the finer fraction of a product runs nearly parallel to that of the feed, while that of a thickened coarse fraction bends downwards sharply. This result has been obtained from numerous classifying trials, both with wet and dry dressing, and also with calculated examples. The distance between the lines for feed and fine product is a measure of the size reduction. A large angle between the lines indicates a sharp classification and less reduction. If the fine product line is more horizontal than the feed line, a disintegration effect is indicated. Investigations to date show that the sharpness of classification can be estimated by the relation between the feed and coarse fraction lines, greater sharpness being indicated by wide spreading and additional steepness in the lower part of the graph.

409. **Particle Size Distribution in Some Ground Ceramic Raw Materials.** VIEWEG, H. F. *J. Amer. ceram. Soc.*, 1935, **18**, 25. Experiments were carried out on typical commercial flints and felspars, analyses being made on three batch-ground felspars, two continuous-ground felspars, two batch-ground flints, and three continuous-ground flints. The batch-ground materials were found to have particle size distributions in the range above 5 microns, characterized by an inverse fourth power size-frequency. The continuous-ground materials had more complex particle size distributions, which are related to those of the batch-ground materials.

410. **A Study of Powder and Granular Ridges in a Sound Field.** WALLER, M. D. *Proc. phys. Soc. Lond.B*, **68** (7), 462–71. The author's vibrating plate method of forming powder ridges on a flat surface is used to study phenomenon with graded powders of different densities and at different frequencies and intensities of sound field. Found that distances between ridges varies as square root of particle diameter. Variables with greatest influence on spacing are grain diameter and frequency—not intensity—of vibration. 18 illustrations, 3 tables, 14 refs.

411. **Calculation of the Surface Area of a Granular Material According to the Rosin–Rammler Formulae.** WEIDENHAMMER, F. *TonindustrZtg*, 1951, **75** (9/10), 133–5; *J. Soc. Glass Tech.*, 1952, **36**, 239. Kiesskalt and Natz (*Z. Ver. dtsch. Ing.*, 1951, **93** (3), 58–60) have confined themselves to values of the coefficient n above 0·6, but many operations necessitate smaller values, and a more detailed consideration of the smaller particles. The results of the calculations now put forward are dependent on the finest particles and on values of n down to 0·2.

412. **A Functional Size Analysis of Ore Grinds.** WEINIG, A. J. *Col. Sch. Min. Quart.*, July 1933, **28** (3), 57.

GRINDABILITY

413. **Grindability, Shatter and Other Tests for Coal.** *See under* Coal.

414. **Measurement of Coal Grindability.** *Fuel, Lond.*, 1955, **34** (3), 367. A Hardgrove type machine has recently been designed and manufactured by H. W. Wallace & Co., Ltd., for measuring grindability of coal for pulverized fuel. The machine conforms to A.S.T.M. Test. Standard D409–37T in handbook D.5 and has been planned at the suggestion of the British Coal Utilization Research Association to accommodate any minor changes in the test which may be found desirable as a result of further research. The 'bowl' or container is a unit complete with pestle and balls, and this can be removed from the machine for filling and emptying. The grinding area of the bowl is also readily detachable. The bowl when charged is lifted upwards against a rubber gasket, and the pestle is rotated under the required load of 64 lb at 20 rev/min for exactly 60 min, after which the machine stops automatically and the bowl is removed for examination of contents.

415. **Pulverizability of Substances.** ANDREASEN, A. H. M., HOFMAN-BANG, N. and RASMUSSEN, N. H. *Kolloidzschr.*, 1939, **86**, 70. Pulverizability is assessed by ability to form an aero suspension. A powdered material is passed through a vertical glass tube

45 mm inside diameter and 2·5 m high and the time required for the material to settle at the bottom of the tube is recorded. Quartz powder 10 mu fine, requires 0·7 seconds in a vacuum and 200 seconds in air, both values being calc. from Stokes law and viscosity of air 0·000189. Calcined flint was ground in a ball mill for 1, 3, 8, 25 hours and the powders tested by this method. Pulverizability number represents the percentage of material still floating in tube after 6 seconds. Flint ground for 1 h has Pu. No. of 21; for 3½ h, 14; for 10 h, 11; and for 25 h, 8. This proves that the pulverizability of a substance decreases considerably with increase in fineness. When finest fractions are removed, an increase in pulverizability takes place.

416. **A Method of Rating the Grindability or Pulverizability of Coal, Developed by the Fuel Research Laboratory.** BALTZER, C. E. and HUDSON, H. P. *Canad. Min. Br.* (*Rep.*), 737, 1933; *Fuel Economist*, 1933, **8**, 703. A 6 lb sample is reduced by successive crushings to 1½ lb, from which a sample of 500 g is taken for first grinding in a pebble mill at 70 rev/min for 1000 revolutions. The residue on 100-mesh sieve is reground after making up to 500 g with original material. A similar third grinding is done and the final residue on 100 mesh is subtracted from 500 g to give the grindability index number.

417. **Standard Grindability Tests and Calculations.** BOND, F. C. and MAXSON, W. L. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1579, 1943; *Ceramic Abstr.*, 1943, **22**, 158. The designs of the 12 × 12-in. ball mill and the 12 × 12-in. long rod mill are described and the results of several hundred tests on various ores are tabulated.

418. **Standard Grindability Tests Tabulated.** BOND, F. C. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 2180, 1947. Grindability data, obtained in standard ball and rod mills, are tabulated for a large range of rocks and ores. Eleven pages of tabulated data are presented on a great variety of materials with respect to standard ball mill and rod mill grindabilities. An extensive table of results of impact crushing tests is also given. Further comparisons are given for impact and compression strengths, additional to those in *Tech. Publ.*, No. 1895, 1946.

419. **Standard Grindability Tests Tabulated.** BOND, F. C. *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1949, **183**, 313. Standard Ball Mill Grindability tests are tabulated for a large number of ores and cements at 28 mesh, 35, 48, 65, 150 and 200 mesh. Over 400 tests are included. Results of over 150 Standard Rod Mill tests are tabulated at various meshes for ores and industrial minerals. Over 80 results of impact crushing tests are similarly tabulated. About 50 results of comparative open circuit grindability tests and standard grindability tests are tabulated.

420. **The Relative Grindability of Coal. The Stevenson Clark Ltd/United Analysts Ltd. (S.C./U.A.L.) Grindability Test.** BROWN, J., IVISON, N. J. and BIRNEY, J. W. Report, Pulverized Fuel Conference, Harrogate, 1947. Institute of Fuel. 2 gns. Relative grindability may be stated in terms of (1) output per hour; (2) power consumption per ton. The term 'What is grindability' is a red herring. The purposes of determining grindability are discussed, a short review of the standard grindability tests is presented, and the aims of the present series of laboratory tests (using an edge-runner mill) are outlined under 9 headings, ranging from the correlation of coals with chemical properties to the effects of size distribution, drying, design of mills, and the petrographic constituents of the coal.

421. **The Grindability of Coal.** BROWN, R. L. *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1946, **10** (1). A survey of earlier work and a discussion of methods of testing is presented. The nature of the problem is outlined and the present position of grindability research is discussed. The evidence available suggests that coal is held together by weak physical forces, that size reduction to a wide range of sizes may be effected by shattering, that it may be also effected by plastic deformation of small particles, that resistance is affected by temperature and atmospheric conditions, and that superfine particles (about 10 mu) are sticky. 10 pp., 35 refs.

422. **Grindability Index Determined by the Ball Mill Method.** BRUNJES, H. L. *Combustion, N.Y.*, 1940, (5), 31–4. Shows how the ball mill method for determination of grindability indexes may be shortened without significant sacrifice in accuracy. The relationships between grindability and friability and volatiles are presented graphically. A curve shows the approximate comparison between the Hardgrove and ball mill methods and a table gives the ball mill grindability index values for 130 coals. 7 refs.

423. **Coal Grindability. A Standard Procedure and a Survey of the Grindabilities of British Coals.** CALCOTT, T. G. *J. Inst. Fuel*, May 1956, **29** (184), 207–17. *See under* Coal.

424. **Correlation of Grindability with Actual Pulverizer Performance.** FRISCH, M. and HOLDER, G. C. *Combustion, N.Y.*, June/July 1933, 29. The general conclusions are: (1) laboratory grinding tests may be used to predict the performance of individual pulverizers, provided that the results of tests on the latter are reduced to a common basis, i.e. to a standard fineness, say, 70% through a 200-mesh sieve and to a normal output; (2) the effect of moisture is important, particularly in the case of non-airswept mills; (3) surface calculations based on surface measurements alone are useless, it being preferable to use the actual percentage passing a 200-mesh sieve as a measure of fineness. (Impact mills were not investigated.)

425. **Coal Friability Tests.** GILMORE, R. E., NICOLLS, J. H. H. and CONNELL, G. P. *Canad. Min. Br.* (*Rep.*) 762, 1935. A study of methods. *See under* Coal.

426. **Determining Grindability of Substances.** GRUNDER, W. *Verfahrenstechnik*, 1938, (1) 17. The energy–time relations for grinding coal and slate in a ball mill coupled to an electrodynamometer. Method of test is described and energy diagrams presented. Summary in *Z. Ver. dtsch. Ing.*, 18 June 1938, **82** (25), 758.

427. **Method of Determining the Grindability of Coal.** GRUNDER, W. *Glückauf*, 1938. 74, 641–6. After reviewing the methods in use especially in America, the author presents an illustrated detailed description of a new apparatus consisting essentially of a cone mill coupled to an electro-dynamometer, whereby power/time graphs are recorded. Interpretation of these graphs is shown by examples.

428. **Grindability of Coal.** HARDGROVE, R. M. *Trans. Amer. Soc. mech. Engrs* (*Fuels, Steam, Power*), 1932, **54**, 37–46. *See under* Coal.

429. **Effects of Grindability on Particle Size Distribution.** HARDGROVE, R. M. *Trans. Amer. Inst. chem. Engrs*, 1938, **34**, 131–52. *Ceramic Abstr.*, 1940, **19**, 20. Very little has been published on the effect of crushing resistance on size distribution. The present paper is intended to show the effect. Conclusions: (1) products having a higher crushing resistance have a lower surface area for the same screen size; (2) knowing the grindability and specific gravity an approximate estimate of the surface can be made for a given screen size; (3) the type of pulverizers or arrangement of circuit has only a minor effect on size distribution compared with the effect of crushing resistance; (4) the data represent a trend only. More work is needed. Ball and ring mills were used for the test (airswept). Grindabilities were by the A.S.T.M. standard (Hardgrove). Crushing resistance = Specific gravity/(Grindability ÷ 100). The grindability indices of nearly 200 materials are given.

430. **Grindability of Alabama Coals.** HERTZOG, E. S. and CUDWORTH, J. R. *Rep. Invest. U.S. Bur. Min.*, No. 3382, 1938. Standard U.S. ball mill method for study of grindability. Sample 500 grams at 10/200 mesh; 740–1400 rev/min. Grindability index is 50 000/Rev. for 80% to pass 200 mesh. In general, the index increases with decreasing moisture content of the coal, but other interesting factors affect the relationship.

431. **Friability, Grindability, Chemical Analysis, High and Low Temperature Carbonization Assays of Alabama Coals.** HERTZOG, E. S., CUDWORTH, J. R., SELVIG, W. A. and ODE, W. H. *U.S. Bur. Min. Tech. Ppr*, No. 611, 1940.

432. **The Determination of Coal Grindability.** HEYWOOD, H. Pulverized Fuel Conference, Harrogate, 1947. Institute of Fuel. 2 gns. The application of the ball mill method and the Hardgrove Mill method to various coals. Results are given in detail and comparisons made. The method of power measurement by dynamometer is described. Among the recommendations made are: The sample for test should represent feed to pulverizer and the product should approximate to P.F. in use. U.S. ball mill method is preferable to Hardgrove; small mills differ from large ones in several effects as regards specific surface, and specific surface to energy ratios. 12 refs.

433. **Effect of Coal Composition on the Performance of Pulverizers.** JUTTE, K. *Brennstoff-Warmetehknik*, March 1954, **6**, 92–3. It is claimed that the Hardgrove grindability index is not always a true index of resistance to grinding. The ash content is not taken into account, although it affects grinding efficiency. The particle size distribution is also left out of account.

434. **Grindability Tester for Testing the Grindability of Hard Materials.** LEHMANN, H. and HASE, U. *TonindustrZtg*, 1955, **79** (7/8), 91–4; *J. Amer. ceram. Soc.*, 1955, **38** (11), 209–10. An apparatus is based on Zeisel's (1953) development of the Hardgrove principle. It consists of a mortar and eight steel balls, 25 mm, on which the lower concave end of a rotating shaft is made to bear. Power is measured by an integrating dynamometer, and grindability is defined as the ratio of increase of specific surface (sq. cm/g) to work input (m-Kg/g). It was found that the grindability of *cement clinker* may vary up to 70% with variation in sintering conditions. Data for *barytes* are given.

435. **Grindability of Various Ores.** MAXSON, W. L., CADENA, F. and BOND, F. C. *Trans. Amer. Inst. min. (metall.) Engrs*, 1934, **112**, 130–45, 161. The authors describe an attempt to simulate industrial conditions of closed-circuit grinding with a ball mill. The method of evaluating screen analysis is described and a comparison of wet and dry grinding is made. A 700-c.c. sample of ore was ground in a ball mill 12 in. by 12 in. at 66 rev/min with 1½-in. to ¾-in. balls, with a 250% circulating load at 100 mesh. After each stage new material was added until the product rate per revolution became constant. [P]

436. **Determination of Ball Mill Size from Grindability Data.** MICHAELSON, S. D. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 123–7; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1844; *Ceramic Age*, 1945, **46**, 141. The calculation of grindability is based on the total power required to grind the material from a certain size of feed to a certain size of product. The type and size of the mill can then be chosen, which will transmit this amount of power. A small laboratory mill was used for the testing, operating at a constant speed of rotation, using a constant volume of ore, and a constant ball load having a relatively constant grinding surface. Certain ores were selected for reference, and different grinding circuits were studied and compared, to avoid error. The variation of the circulating load between 100% and 1000% was found to have little effect on the grindability; another study, with the aim of developing a basis for comparing capacity with different percentages of minus 200-mesh material in products, revealed that the capacity decreased in inverse ratio to the relative grindabilities. Regarding both the capacity and power per ton of grinding media of an overflow mill as 100%, it was determined that the relative capacities of an intermediate-level grate mill and low-level mill would be 115% and 120–125%, and the relative powers about 111% and 116–120%, respectively. From the relevant data in any particular case, the net production required from the ball mill circuit is ascertained, and the size is then calculated for the type of mill to be employed. An example is given in full.

437. **A Study of the Grindability of Coal and the Fineness of Pulverized Coal when Using the Lea-Nurse Air Permeability Method for Evaluating the Subsieve Fractions.** ROMER, J. B. *Proc. Amer. Soc. Test Mater.*, 1941, **41**, 1152–66; Discussion 1167–71. The methods for determining the sieve size of pulverized coal are discussed. There is need for a better evaluation of subsieve fractions. The use of specific surface data by

such methods as the L.N. method is discussed. It is considered that the data obtained by such methods bring the results in better alignment with the requirements of Rittinger's law. 9 refs. *See under* Coal.

438. **The Dependence of Grindability of Cement Clinker and Limestone on the Properties of these Materials.** SCHMID, A. *Schriftenreihe der Zement-Industrie*, 1953, **14**, 7–29. Grindability is related to the physical and chemical properties of the charge. For cement clinker it is inversely proportional to resistance to impact. A knowledge of the composition and physical properties of clinker and related materials enabled their grindabilities to be predicted. The grindabilities can be measured by a modified Hardgrove method, where the surface produced can be related to work input. A new impact machine is illustrated. The relations between grindability as indicated by surface area production and the properties of the materials are presented in twelve graphs, 7 refs. Quotes: Tavasci, B. Structure and Grindability of Portland Cement Clinker. *Zement*, **30**, 1941, 423–9, Zeisel, H. G. Development of a Procedure for Determining Grindability, Dissertation, Aachen, 1952.

439. **Check Determinations of the Grindability of Coal by Various Methods.** SELVIG, W. A. *Rep. Invest. U.S. Bur. Min.* No. 3301, 1936; *Fuel, Lond.*, 1936, **15**, 156; *Pwr Plant (Engng)*, 1936, **40**, 723. Soft and medium coals were tested in five laboratories using the Bureau of Mines ball mill method, the Cross and Fuel Research Laboratory, Canada, ball mill methods and the Hardgrove method. The Cross and F.R.L. methods showed the greatest variation in results, both among duplicate determinations and among laboratories, over 100% variation being shown, as against about 4% by the Bureau of Mines method. The mean values are tabulated for the grindabilities of the five coals by the Hardgrove and Bureau of Mines methods.

440. **Relative Grindability of Coal.** SLOMAN, H. J. and BARNHARD, A. C. *Trans. Amer. Soc. mech. Engrs*, 1934, **56**, 773–9. The Carnegie Institute of Technology method is described. This consists of a steel roller being allowed to run down an inclined steel plane over 20 grams of coal graded between 20- and 30-mesh sieves. The surface units are calculated by the Hardgrove method, except that sedimentation analysis has shown that a factor for the −300-mesh fraction should be 3000 instead of 1000. The results of tests appear to agree well with those of the Hardgrove method, but not with the F.R.L., Canada, and the Cross methods. The need for a standard grindability test for various coals is pointed out.

441. **Estimation of the Grindability of Coal.** YANCEY, H. F., FURSE, O. L. and BLACKBURN, R. A. *Trans. Amer. Inst. min. (metall.) Engrs*, 1934, **108**, 267. The paper describes the research on a small ball mill made by the U.S. Bureau of Mines, which led to the specification for coal grindability testing by the A.S.T.M. Surface measurements were eliminated from the procedure on account of the difficulty in determining the specific surface of the finest materials. A full summary is given by Heywood in *Combustion Appliance Makers' Association Document* No. 1657, 1938, pp. 57–62, together with a drawing of the mill.

442. **Further Investigation of Methods for Estimating the Grindability of Coal.** YANCEY, H. F. and GEER, M. R. *Trans. Amer. Inst. min. (metall.) Engrs*, 1936, **119**, 353–77. A comparison is given of the C.I.T. roll test, the Bureau of Mines ball mill method and the Hardgrove machine method. The ball mill method is the only one specifying a final size such as that of powdered fuel. With admixture of harder impurities the ball mill method is the only one to represent accurately the grindability. A summary with tabulated results is given by Heywood in *Combustion Applicance Makers Association Document*, 1657, 1938, pp. 63–4.

443. **Development of a Procedure for Determining Grindability.** ZEISEL, H. G. *Schriftenreihe der Zement-Industrie*, 1953, (14), 31–72. The grindability of a number of materials has been tested in a Hardgrove vertical annular ball mill and a quantitative

expression is put forward. The materials tested were cement raw materials, rock crystal, fluorspar, barytes, coke and coal. Surface area measurements of the products were related to the grinding variables measured and it was found that maximum ease of grinding was recorded for a particular surface area to weight ratio for a given material and for a given set of mill conditions. The most important governing factor was the initial particle size. Calculations showed that neither the Rittinger nor the Kick laws were valid for the products obtained. 41 refs.

444. **Crushing Resistance of Minerals.** ZIMMERLEY, S. R. and GROSS, J. *Rep. Invest. U.S. Bur. Min.*, No. 2948, 1929. The values were determined by the same apparatus and method as used by the authors for crushing quartz. Results are tabulated for pyrites, sphalerite, calcite, three samples of galena and quartz.

DIFFERENTIAL GRINDING

445. A **Preliminary Investigation of Differential Grinding. Grinding of Quartz-Limestone Mixtures.** HOLMES, J. A. and PATCHING, S. W. F. Atomic Energy Research Establishment, Harwell, CE/R1887, 1956, 29 pp. Mixtures of quartz and limestone in varying proportions have been ground with the object of determining the effects of variation in amounts and also of the mesh of grid on the behaviour of the components. Closed circuit was used. The conclusions from the investigation are recorded at some length. It was found that the rate of reduction of each component was reduced by the presence of the other, but the proportions of the components had no effect on the specific rates of grind for any one mesh, the specific rates being related to the bulk volumes of the components. There was no effect on the resulting size distribution of either component due to differential grinding. Change in the mesh of grind altered the rate of grinding of each component very nearly in the manner which could be predicted from their individual specific rates of grind. The methods of treatment outlined should be applicable to studies of mixtures of other components, and possibly to components locked together in composite rock, and thus to the possibilities of differential grinding of ores. 13 graphs, 3 refs. (*See also* Nos. 506, 699, 1481, 1539, and 2129.)

ADSORPTION OF ELECTROLYTES AND OXYGEN

446. **Adsorption of Electrolytes on Fine Pulverized Minerals, Conductometric Studies.** BRING, G. G. *Jernkontor, Ann.*, 1954, **138** (11), 671–701. 17 illustrations, 16 tables, 26 refs.

447. **Absorption of Atmospheric Oxygen (During Grinding) in a (Steel) Ball Mill.** LIUTIN, L. V. *Zh. prikl. Khim. Leningr.*, 1941, **14**, 790–3. The absorption of atm. oxygen during grinding in a steel mill using steel balls was investigated by measuring the decrease of pressure in the mill after wet-grinding at 60 rev/min. Absorption was greater when using distilled H_2O (I) than with the following aq. solutions: 0·1N-NaCl; 0·0005N-, 0·0015N-, and 0·01N-Na_2CO_3; 0·01N-$Na_4P_2O_7$, and 0·05N-$K_2Cr_2O_7$.

Absorption decreased with increasing pH values. An aq. suspension of quartz sand or kaolin showed a value somewhat less than that of (I), but that of an aq. suspension of graphite was approx. twice that of (I). Oxygen was not absorbed when machine oil or a mixture of 2½% H_2O–97½% machine oil was ground. Absorption is attributed to the oxidation of the fine particles of iron derived from the mill materials and dispersed throughout the medium being ground.

VISCOSITY EFFECT

See under Fine Reduction.

USE OF RADIOACTIVE TRACERS

448. **Radioactive Isotopes in Mineral Dressing Research.** CARR, J. S. *Recent Developments in Mineral Dressing*, 465–501. 1953, Institution of Mining and Metallurgy,

Atomic Energy Research Establishment, Harwell, CE/R/912, 1952. Their use will be extended for study of pulp density, mill speed, preferential grinding and particularly the effect of circulating load.

The lines on which the phenomena of grinding can be investigated are put forward (Na^{24} is a convenient isotope to use).

449. **Progeny in Comminution.** GAUDIN, A. M., SPEDDON, H. R. and KAUFMAN, D. F. *Min. Engng, N.Y.*, 1951, 3, 969–70; *Tech. Publ. Amer. Inst. Min. Engrs.* No. 3171; Abstract in *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1952, 16 (2), 72. An investigation of the size distribution, after grinding, of a particular size fraction mixed with other fractions using the radioactive tracer technique. The results of the preliminary experiments with feed sizes ranging from 10–14 to 100–150 suggest that fracturing of one size in a normal environment of all sizes may produce relatively fewer fines than if a feed of one size is crushed or ground. Albite was used in this case, sodium being the radioactive metal. Applications to crushing investigations are suggested, particularly on circulating loads.

450. **Radioactivity in Mineral Dressing.** GAUDIN, A. M. *Trans. Instn Min. Metall., Lond.*, Nov. 1952 (552), 29–42. The third Sir Julius Wernher Memorial Lecture given at the Royal Institution, London, Sept., 1952.

Crushing and Grinding Practice

HISTORICAL

451. **Corn and Paint.** *Res. Ass. Brit. Paint, Col., Varn. Mfrs, Monthly Memo.*, No. 112, 1953. A survey of the various devices leading probably from ancient corn-grinding mills to present-day paint mills. The process is traced briefly from primitive pestle and mortar, through the saddle mill (stone roller pushed backwards and forwards on a flatstone bed), quern mill (two flat stones), cone mill (to assist in the discharge of ground corn to water-powered flat stone mills (Roman 6th century) and then wind mills and in 1786 steam-driven flat-stone flour mills. Roller mills (for sugar cane) with vertical wood rolls (1449) are included.

452. *De Re Metallica.* AGRICOLA (Georgius). 1950, Dover Publications, New York. 638 pp. Translation from the first Latin edition 1556 by Herbert Clark Hoover and Lou Henry Hoover. Biographical introduction, annotations and appendices on the development of mining methods, metallurgical processes, geology, mineralogy and mining law from the earliest times to the 16th century. Includes descriptions of the construction and operation of early stamp mills powered by water wheels and draft animals, also all of the 289 16th-century drawings and a full list of Greek, Roman and medieval authors in mining or metallurgy whose works were available to Agricola. Hoovers' translation, the first into English, appeared in abridged form in the *Min. Mag., Lond.*, in 1912. An appreciation of Agricola's work is given in *Discovery*, July 1956, **17** (7), 294–6.

453. **The Development of Ball and Roller Mills.** BACHMANN, D. *Chem. Tech., Berlin*, 1942, **15**, 198.

454. **The Development of the Vibration Mill.** BACHMANN, D. *Chim. et Industr.*, 1943, **50** (10), 256. *See under* Vibratory Ball Mill.

455. **History of Corn Milling.** BENNETT, R. and ELTON, J. Simpkin, Marshall & Co., London, 1898–1904, 4 vols. Includes descriptions of many varieties of grinding mortar.

456. **Fine Grinding.** COGHILL, W. H. *J. Amer. Zinc. Inst.*, 1929 **12** (5/6), 100. Account of early history and development of the ball mill.

457. **Conclusions from Experiments on Grinding.** COGHILL, W. H. and DE VANEY, F. D. *Bull. Mo. Sch. Min.*, 1938, **13** (1), 100 pp. Early history of size reduction. Modern history. The ball mill. Three industrial epochs. *See* No. 1060 *et seq.*

458. **Micromeritics.** DALLAVALLE, J. M. Pitman, New York, 2nd Edition, 1952. Historical aspects are given in the various particle science sections. *See under* Size and Surface Area.

459. **Development of the Stone Breaker.** DICKINSON, W. H. *Cement, Lime & Grav.*, 1945, **20** (3), 78–83. The author presents a historical review, from breaking by hand to the modern jaw crushers, jaw granulators, roll and gyratory crushers.

460. **The Evolution of Mills for Grinding.** FISCHER, E. K. *Interchem. Rev.*, 1944, **3** (4), 91–104. This historical survey is illustrated by woodcuts, drawings and photographs of mills dating from ancient times to the end of the 19th century (early pebble mill), and representing the practice of many countries. Forerunners of modern design improvements can be observed. Twenty-four references are appended. These refer to the history of manufacture of various products and to general works which include historical material.

461. **Internal Mechanism of Ball Milling.** JOISEL, A. and BIREBENT, A. *Rev. Matér. Constr. C*, 1951, (434), 311–20. A historical review.

462. **Fine Grinding Machines.** KLAR, H. *Ber. dtsch. keram. Ges.*, 1929, **10**, 285–313. Description with diagrams of the development of cone mills, bowl, pan and ball mills. Finally the high-output Hildebrandt ball mill is described wherein small balls 8 to 15 mm diameter are circulated at high speed with the material to produce very fine powder.

463. **A Historical Survey of Crushing and Grinding Equipment.** LEBETER, F. *Mine & Quarry Engng*, 1949, **15**, 271, 307–11, 385.

464. **Crushing Theory and Practice.** MCGREW, Brownell. *Rock Prod.*, 1950, **53** (6), 118–20. Part 1. Historical Summary. Development of crushing equipment in U.S.A. from the drop hammer of 1830, the first U.S. Patent. In 1840 a forerunner of the hammer mill was patented and consisted of a box (wood) containing a drum (wood) provided with iron knobs or hammers. It was expected that when revolved at 350 rev/min it would shatter the rock loaded into the top of the box. This, however, bore a closer resemblance to the single sledging roll crusher. Eli Whitney Blake invented the first mechanical jaw breaker, embodying the powerful toggle linkage. It is the standard of comparison today for all jaw crushers for heavy duty. The gyratory principle had several rudimentary designs between 1860 and 1878, but in 1871 P. W. Gates took out a patent which included all the essential features of the modern gyratory crusher. Gates became famous. In a contest in 1883, in Connecticut, the Gates crusher finished 9 cu. yd of stone in 20½ minutes as against 64½ minutes for a Blake crusher, feed and product size being similar. Stamp mills accomplished the fine reduction after the crushers. At Homestake, 22 small Gates crushers prepared the ore for 2500 stamps, i.e. duplication rather than increase in size. The steam shovel for quarrying led to larger crushing units. By 1910, crushers with 48-in. openings were made. At this time the jaw crusher revived in popularity, having an opening 84 in. by 60 in. At the beginning of 20th century, Edison, from energy cost (explosive v. coal) considerations, built his famous 8 ft × 7 ft roll crusher, but it never became popular. The more versatile jaw and gyratory crushers remained popular, but smaller sizes of rolls were used by Edison in his own cement mills. At the beginning of this century, primary sledging roll crushers were developed 36 in. diam. × 60 in. face, for limestone. These became popular and became as big as 60 in. × 84 in. Small smooth-faced crushing rolls became popular for smaller sizes before the end of last century, but no other fine crushing development occurred.

465. **Chemistry of Fine Grinding.** MARTIN, G. *Industr. Chem. Mfr.*, 1926, **2**, 409. Abstract of paper read before the British Association at Oxford, Aug. 1926. *See under* Fundamental Aspects, General Papers.

466. **The Evolution of Various Types of Crusher for Stone and Ore.** MILLER, W. T. W. and SARJANT, R. J. *Min. Proc. Instn civ. Engrs*, 1934–5, **239** (1), 39–95; *Trans. ceram. Soc.*, 1937, **35**, 492; *Road Abstr.*, 1936, 3, 622.

467. **The First Stamp Mills in English History.** SHUBERT, H. R. *J. Iron St. Inst.*, Nov. 1947, **157**, 344. Eleven historical refs. are given. Relate chiefly to minerals or metals. Vertical stamp mill working in a mortar dates back to 1500. One of the oldest types. First introduced into England by the Germans, whose skill was admired.

468. **Ball and Tube Mills.** STRODER, E. *TonindustrZtg*, 1913, 37 (46), 608–10. The idea of combining the ball mill with the tube mill is not new, but the building of such machines began only three years ago. The development is described and illustrated pp. 1172–3. Reply to criticism by Beneke reported on p. 608.

469. **Grinding and Sifting.** TUBMAN, F. de M. *Chem. & Ind.* (*Rev.*), 1932, **51**, 330. Detailed discussion of ancient and modern methods of grinding and sifting. Many kinds of machines are described, and it is mentioned that rubber lining grinds as effectively as steel liners.

470. **Recent Tests of Ball Mill Crushing.** VAN WINKLE, C. T. *Trans. Amer. Inst. min. (metall.) Engrs*, 1918, 227–48. Describes the introduction of tube mills for ores, to do in one pass what the stamps, rolls and Huntingdon mills could not do. Pebbles became the medium in tubes 20 ft long. Ball mills were in use outside U.S.A., but were small and costly.

471. **Milling.** WAESER, B. *Kolloidzschr.*, 1952, **126**, 149–53. A historical review leading to the present position of grinding theory, accompanied by references to 26 important contributions and to certain other authorities. A historical review of the patent literature is presented and finally modern technical advances are discussed. 26 refs.

GENERAL PAPERS

472. **Ore Grinding.** For papers dealing more specifically with ores, *see under* Ores.

473. **Symposium on Comminution.** *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 12–202. 19 Papers presented on Comminution, 7 on Sedimentation, 5 on Flotation, 1 on Drying and Calcining, 7 on Milling Practice, 7 on Mill Design, 2 on Metallurgical Analysis.

474. **Symposium on Comminution.** *Min. Engng, N.Y.*, 1950, **2**; *Trans. Amer. Inst. min. (metall.) Engrs*, **187**. HARDINGE, H., and FERGUSON, R. C., 1127–30, Effect of Mill Speeds on Costs. MYERS, J. M., and LEWIS, F. M., 1133–6, Progress Report. Ball Consumption at Tennessee Copper Co. NORQUIST, D. E., and MOELLER, J. E., 712–4, Relative Rates of Wear of Various Diameter Balls in Production Mills. STROHL, J. J., and SCHWELLENBACH, H. J., 1273–4, Effect of Rod Mill Feed Size Reduction. BOND, F. C., 1149–50, Discussion on the Effect of Mill Speeds on Grinding Costs. ROBERTS, E. J., 1267–72, The Probability Theory of Wet Ball Milling and its Application. BOND, F. C., and WANG, J. T., 871–8, A New Theory of Comminution. SUN, S.C., and MORGAN, J. D. and WESNER, R. F., 369–73, Mineral Particles in electrostatic separation. FINE, M. M., 385–90, Production of Graded Glass Sand by Grinding and Classification.

475. **Non-Ferrous Ore Dressing in the U.S.A.** *Report of Technical Assistance Mission No.* 54, 1953, O.E.E.C., Paris. Obtainable from H.M. Stationery Office. *See under* Ores.

476. **Ore Dressing and Cement Machinery in Germany. 1939–1945.** *B.I.O.S. Final Report*, No. 1587, Item 31. H.M. Stationery Office.

477. **Change of State in Aggregation.** ANON. *Chem. Engng*, 1948, **55** (5), 103–5. Disintegration remains an empirical art. Recognition of the waste of power due to over-grinding has favoured continuous grinding with classification of the product and return of the oversize. Jet pulverizers are replacing mechanical types where particles of average size 5 mu are required. Electrostatic spraying for finishes and enamels gives greater uniformity of coating and obviates loss of materials.

478. **Pulverizing 200 Process Materials.** ANON. *Chem. metall. Engng*, May 1938, **45**, 241–2. A tabulation of the answers of 43 manufacturers of pulverizing equipment when asked 'Which of these raw materials has been successfully ground by your equipment?' [P.]

479. **High Lights in Milling, 1952.** ANON. *Engng Min. J.*, 1953, **154** (2), 121–2. General review. 'No such thing as overgrinding.' 'Tendency to revert to pebbles.' 'Rod mills continue to gain ascendency over rolls.'

480. **Crushing and Grinding. A Staff Survey of Recent Developments.** *Int. chem. Engng*, 1948, **29** (7), 304–10. The review includes a classification of crushing and grinding operations, illustrations of the Kibbler mill, Attritor Unit for Coal, Symons Intermediate Cone Crusher (high output and high ratio of reduction), Simon Type G

roller mill with automatic throw out gear, the Hydrol single roll mill, and an illustrated table of non-mechanical pulverizers taken from the *Mon. Bull. Brit. Coal Util. Res., Ass.*, 1947, **11** (7), 221. Accounts of industrial practice at four U.S.A. ore or smelting plants are included. 57 refs.

481. **Developments in Modern Pulverizing Equipment.** *Min. J.*, 20 Nov. 1953, **241**, 590–1. Types of mills and their applications, with special reference to *pilot plants*, dealing particularly with German equipment. Eight German firms are referred to: R. Liebau, Chemnitz; L. Hormuth, Heidelberg; Thieme & Towe, Halle; Lehmann, Dresden; Maschinen-Fabric Geislingen, Heidelberg; G. Eirich, Hardheim; Gaspery, Leipzig; Vogele, Mannheim. Greater attention than ever before is being paid to the reduction to small size of metalliferous ores and residues. 9 refs.

482. **Gradation of Crushed Material and the Problem of Cubic Material.** ANON. *Pierres et Min.*, 1934, **6** (61/62), 980–1. In descending order of effectiveness for cubic material: (1) indented curved (gyratories) (not commercially practical); (2) indented, rectilinear (jaw crushers, crushing rolls); (3) smooth, slight curvature (gyratory granulators); (4) smooth, large curvature (cone crushers); (5) smooth, rectilinear (crushing rolls and disc crushers). *See further under* Aggregate.

483. **Reducing Grinding Costs.** ANON. *Rock Prod.*, 1942, **45** (1), 64–6. Describes the use of various grinders and makes suggestions for reducing costs.

484. **Some Investigations on Crushers.** Statens Vaginstitut Stockholm. *Meddelande* No. 55. 1937, 84 pp. (In Swedish with English Summary.) The results are reported of investigations carried out on five jaw crushers, a special disc crusher, and three impact breakers. The crushers were of the types and sizes generally used in road construction, and the tests were made with various rocks. The factors studied were size, flakiness, and strength of the product and the output and power consumption of the crushers. It was not found that the type of rock affected the grading and shape of the crushed products to any marked degree. 42 figs., 21 tables. [P.]

485. **How to determine Crusher and Grinding Mill Sizes—Accurately.** Allis Chalmers Co. (Milwaukee). Supplement to Catalogue, 1953, pp. 1–72. On pages 1–6, the method of calculating the work required to crush or grind to a given size reduction based on Bond's theory is given. From the calculated kW or h.p. per hour requirements, it is shown how to select the appropriate, gyratory crusher, rod or ball mill, from the tables of equipment sizes and characteristics as put forward by the makers.

A work input graph shows work requirements for reducing materials to a range of sizes from 1000 to 100 microns at reduction ratios from 1·5 to 1000.

On pp. 7–72, three tables are compiled from data obtained in the years 1929 to 1952, showing the Work Indices (W.I.) for a large number of rocks and minerals including varieties. These are arranged according to (1) operating firm, (2) materials, (3) averages of varieties of materials. In all, some 1200 work indices are tabulated, which have been calculated from test data obtained at many company locations and from various types of crusher and grinders. Finally, materials are tabulated in alphabetical order (59) with average W.I. from preceding tabulations.

486. **Comminution Machine Considered on a Basis of Similarity.** ANDREASEN, A. H. M., JENSEN, I. H. *Z. Ver. dtsch. Ing.*, 21 Nov. 1954, **96** (33), 1117–20. By comparison of large and small mills and model tests, a survey on the economy of various mills, e.g. jaw breakers, cone breakers, can be obtained. This applies to other mills under certain conditions.

487. **Some Fundamental Principles of Fine Grinding.** ANDREWS, L. *Paint Tech.*, 1942, **7**, 111–14, 147–9, 165–7, 183–6, 201–4; 1943, **8**, 19–22. The articles are instalments from a book to be published by the author on grinding. The mode of action and motion of balls in a ball mill are explained with many diagrams and illustrations, and the causes and mode of wear of liners are also well illustrated. Causes of inefficiency are described.

488. **Pulverizing Plant.** BABCOCK & WILCOX, LTD. *Brit. Pat.* 577507, 1944/46. Provision is made for recirculation of air and oversize material, for automatic feed and for air control, and control of output.

489. **Difficulties with Quarry Plants and Some Remedies.** BARTON, L. V. *Quarry Mgrs' J.*, 1933, **16** (9), 298–300. Discusses the relation of the type of rock to the most suitable form of crusher. Abstract in *Road Abstr.*, 1934–5, **1**, 25.

490. **Modern Machines for Dry Size Reduction in Fine Size Range.** BERRY, C. E. *Industr. Engng Chem.* (*Industr.*), 1946, **38**, 672. Machines of the type of the ball mill, the ring roll, and the hammer mill, operated either in open or closed circuit with size classifiers, have been available for many years for the production of fine materials. More recently high-speed hammer mills and fluid-energy mills, nearly all with integrally fabricated size classifiers, have become available as the result of a demand for the production of still finer materials. Average size specifications of 20 microns and smaller, as determined by microscope examination and air permeability methods, are becoming common. The Mikro-Atomizer and the Raymond vertical mill are machines of the high-speed rotor design. The Micronizer, the Reductionizer and the Eagle mill are all machines of the fluid-energy type which utilize compressed air or high-pressure steam to effect the desired size reduction.

491. **How Does a Coal Pulverizer do its Job?** BLUM, J. K. *Power*, 1928, **68**, 100. A good summary of the processes of pulverization. They are classified into five mechanisms and into four aspects of energy expenditure: heating, moving, breaking or deforming particles, and windage and friction losses.

492. **Crushing and Grinding Characteristics as Determined by Screen Analysis.** BOND, F. C. and MAXSON, W. L. *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1935, **112**, 146; *Milling Methods*, 1934.

493. **The Reduction Ratio Curves for Crushing and Grinding.** BOND, F. C. *Engng Min. J.*, 1938, **139** (7), 48. Discussion of reduction ratio. The accumulation of a series of reduction curves covering various materials and machines and conditions, would greatly facilitate the study of mineral comminution, and allow the proper machine to be chosen for a desired size distribution of product. The design of new machines would be facilitated.

494. **Principles of Crushing.** BOND, F. C. and BRIBER, F. E. Jr. *Pit & Quarry*, 1951, **44** (1), 173–6. The theory of crushing, energy input required, particle size and shape relationships, crushing tests and the application of various types of crusher are discussed. 3 figs.

495. **Mathematics of Crushing and Grinding.** BOND, F. C. Symposium on Mineral Dressing, London, Sept. 1952, Paper No. 2. Institution of Mining and Metallurgy. Theory put forward—the total work input represented by a given weight of a crushed or ground product is inversely proportional to the square root of the diameter of the product particles. Expressions involving work index are developed.

Factors affecting the capacity of jaw crushers: Metal wear is not predictable but the cost approaches the power cost. Dry v. wet grinding. Volume of grinding charge. Pulp dilution. Mill speeds. Grinding media, size distribution. Mill diameter (ball and rod mills). Other factors are also considered. Summarized calculations of machine, crusher and ball mill sizes. 8 refs. See also *Min. Engng, N.Y.*, 1952, **4**, 484; *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1952, 407; *Recent Advances in Mineral Dressing*, 1953, Institution of Mining and Metallurgy.

496. **Which is the More Efficient Rock Breaker?** BOND, F. C. *Engng Min. J.*, 1954 (1), **155**, 82. *See* No. 30.

497. **Unit Operations.** BROWN, G. G. AND ASSOCIATES. 1950, Wiley & Sons, New York, Chapman & Hall, London, pp. 25–49. Size Reduction of Solids. A description with illustrations of crushing and grinding equipment, the mechanisms of the respective

crushing or grinding actions and capacity tables, with a more lengthy treatment of ball and rod mills, and a section on energy requirements. A dozen problems are set, based on tabulated data provided. 6 refs.

498. **Maintaining Milling Equipment.** BROWN, H. M. *Brick, Clay Rec.*, 1952, **121** (3), 58–9. How production delays and milling costs can be reduced by proper maintenance. Engineering details are given.

499. **The New Central Crushing Plant at Lake View and Star Ltd.** BUCKETT, R. C. *Proc. Aust. Inst. Min. Engrs*, 1948 (148–9), 87–109. The original (1930) and new central crushing plants are described in detail. Factors influencing the decision to rebuild were (1) requirement of additional screens for reducing the finished product size, (2) to lower the crushing costs (better feeding arrangements, etc.), (3) the need to replace wooden conveyors. *Inst. Min. Metall. Abstr.*, Dec. 1953, p. 107.

500. **Crushing and Grinding.** CAREY, W. F. *Trans. Instn chem. Engrs, Lond.*, 1934, **12**, 179. An outline is given of the manner in which homogeneous brittle substances fracture when crushed freely. In a discussion of existing crushing machines it is concluded that (1) ball mills and ring rolls will always tend to form aggregates, and (2) impact machines will either suffer excessive windage losses, due to air friction and movement, or fail to fracture a large proportion of the particles which are hit.

501. **Some Modern Methods of Milling of Industrial Materials.** CARNOCHAN, R. K. *Trans. Canad. Min. Inst.* (*Inst. Min. Metall.*), 1939, **42**, 29–34. A brief account of crushing and grinding methods for minerals and of the methods of separation.

502. **Contrasts in Grinding Characteristics of Mineral Products.** COE, G. D., and COGHILL, W. H. *Rep. Invest. U.S. Bur. Min.* No. 3704, 11 pp.; *Ceramic Abstr.*, 1943, **22**, 142. The report contrasts the net energy consumed in grinding to a top limiting size and size distribution of ground products for a number of minerals, including talc; sphalerite, topaz, limestone, siderite, chalcopyrite, rutile, quartz, chalcedony, zircon, bituminous coal, anthracite, bighead cannel coal, taconite, chert and cement clinker. The report was prepared in co-operation with the University of Alabama. [P.]

503. **Determination of Flakiness of Ores.** COGHILL, W. H., HOLMES, O. W. and CAMPBELL, A. B. *Rep. Invest. U.S. Bur. Min.* No. 2899, Oct. 1928, 7 pp.

504. **Conclusions from Experiments in Grinding.** COGHILL, W. H. and DE VANEY, F. D. *Bull. Mo. Sch. Min.*, 1938, **13** (1), 100 pp., 69 refs. *See* No. 1060 *et seq.*

505. **Particle Size Reduction and Separation.** COGHILL, W. H. *Trans. Amer. Inst. chem. Engrs*, 1938, **34**, 113; *Ceramic Abstr.*, 1940, **19**, 21.

506. **Differential Grinding of Alabama Ores.** COGHILL, W. H. and DE VANEY, P. H. *Rep. Invest. U.S. Bur. Min.*, No. 3523, 1940. *See under* Iron Ore.

507. **Types of Grinding Mills and When to Use Them.** ERICKSON, H. W. *Chem. Engng Progr.*, 1953, **49** (2), 63–8. Illustrated account of various grinding mills. The advantages of classification during grinding to avoid overgrinding and waste of energy. The equipment is classified into ball mills, tube mills (pebble mills and ball peb., or long ball mills, the latter having iron or steel balls), compartment mills (combination of ball mill and tube mill), grinding in stages, rod mills, peripheral screen ball mills (Krupp mills), batch mills (ball) and a description of their applications, Rolls, Roller Mills (pan and ring), impact pulverizers (hammer, fluid energy such as micronizers) attrition and buhrstone mills. Precautions against toxicity, softening of charge, inflammability of product.

508. **Crushing Machines for Coke and Coal Samples.** EHRMANN, K. and SPORBECK, H. *Glückauf.*, 12 Feb. 1955, 91, 7/8, 187–93. Review, critical examination and comparison of crushing machines, etc., abrasion resistance, time of crushing, power requirements, freedom from dust, cleaning, noise, safety design, and efficiency. 19 illustrations.

509. **Process Technique in Size Reduction.** ESCHWERKE, A.G. (Duisberg). *Cement-Kalk-Gips.*, 1953, **6** (7), 261. Information brochure on grinding practice which should prove of great help to process engineers.

510. **Flotation Practice at the Coeur d'Alene District. Idaho.** FAHRENWALD, A. W. *Trans. Amer. Inst. min.* (*metall.*) *Engrs* (Flotation Practice), 1928, 107, 132. States the advantages of a high circulating load. Laboratory experiments indicate greater efficiency with higher pulp densities. Poor classification results in lower mill capacity and in overgrinding.

511. **Progress in Milling Practice and Equipment.** FAHRENWALD, A. W. *Min. Congr. J., Wash.*, 1940, **26** (1), 17–22. A general account of principles of comminution and the application to various aspects of ore dressing.

512. **A Method of Predicting the Performance of Commercial Mills in the Fine Grinding of Brittle Materials.** FAIRS, G. L. *Trans. Instn Min. Metall., Lond.*, 1953–4, **63**, 211–40. 23 refs. *See* No. 61.

513. **Modern Grinding.** FARRANT, J. C. *Trans. Soc. chem. Ind., Lond.* (Chem. Engng Group), 1931, **13**; *Chem. & Ind.* (*Rev.*), 1931, **50**, 94–6. An account of the paper under this title (32 pp.) read by the author at the Society of the Chemical Industry meeting on 23 Jan. 1931 at Derby. The paper is confined to fine grinding, and classifies the mills for this purpose as (1) slow-speed (attrition and impact, e.g. ball mills), (2) medium-speed (compression, e.g. pan, ring roller mills) and (3) high-speed (impact and shearing, e.g. hammer and similar mills). The characteristics of these types are described, illustrated and accompanied in some cases by graphical and tabular presentations of performance and operational data. A large section is devoted to operational and product data in tabular form for numerous materials and their varieties when ground in the various types of mills, whereby comparisons can be made between different types of mill for a particular material. 45 illustrations and diagrams. Other accounts in *Chem. Tr. J.*, 1931, (88), 97–9; *Chem. Age, Lond.*, 1931, **24**, 68; *Crush & Grind.*, Sept.–Oct. 1931, **1**, 55–6. [P]

514. **A Review of Certain Unit Processes in the Reduction of Materials.** FARRANT, J. C. *Trans. Instn chem. Engrs., Lond.*, 1940, **18**, 1–20. The paper is an attempt to clarify certain misunderstandings that have arisen through the publication of technical details covering a specific process, but which tend to obscure fundamentals. The first section deals with the mechanism of primary crushing and the main aspects of power consumption. A second section deals with screening and a third section with the mechanism and performance of various types of grinding equipment. A comparison of open and closed circuits is made and performance data from industrial equipment is presented. A fourth section deals with the pumping of slurries, a fifth deals with automatic control of grinding equipment and a sixth with types of cascade mill. [P]

An account is given in the *Chem. Tr. J.*, 1940, **106**, 257 and 273.

515. **Fuel Efficiency Lectures. Grinding Plant.** FARRANT, J. C. *Chem. Age, Lond.*, 1944, **50**, 101–4. Deals with various aspects of grinding: Variation in size of feed, moisture in feed (it frequently pays to dry a moist feed), general maintenance, overload factors, the merits and the varying necessity of crushing before grinding, optimum speed and selection of the right type of mill.

516. **The Evolution of Mills for Grinding.** FISCHER, E. K. *Interchem. Rev.*, 1944, **3**, 91–104. A historical review of the development of grinding mills. Range and utility of various mills are defined in terms of clearance between the mill surfaces, the velocity relative to each other, and the plastic viscosity of the composition being milled.

517. **Pulverized Fuel Technique.** FITTON, A. *Inst. Petrol. Rev.*, 1949, **3** (1), 18–26. A review of slow and high speed pulverizers. *See under* Coal.

518. **Unusual Techniques in Grinding.** FOOTE, J. H. *Chem. Engng Progr.*, 1953, **49** (2), 68–72. (1) Grinding atmosphere; temperature, moisture; composition; liquid nitrogen.

(2) Grinding in the form of slurries or sludges. (3) Pretreatment; sizing; grinding aids. (4) After-treatment. (5) Use of inert atmospheres; chemical reactions during grinding. (6) Use of different types of equipment in tandem for special characteristics.

Also: precautions re cast iron and cold resisting alloys; pre-crushing of fibrous roots between heavy rollers, before grinding.

519. **Can the Result of Grinding be Predetermined?** FRENAY, E. and COLLEE, R. *Rev. univ. Min.*, 1950, **6** (11), 370–9; *Amer. Ceramic Abstr.*, 1951, **34**, 76. The result of a comminution (grinding, crushing) process of a material to a certain size without a too large proportion of oversize or very fine particles can usually be determined only after the process. An attempt is made to develop, from the physical data of the equipment, a graphical method of guiding the grinding operation in such way as to obtain a product of sizes between certain dimensions. Examples using normal equipment for grinding ores or clinkers are given.

520. **An Investigation of Crushing Phenomena.** GAUDIN, A. M. *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1926, **73**, 253–310. A comprehensive study of the mechanism and phenomena of reduction in jaw crushers, roll mills, rod and ball mills. Performance data and wear tests are presented in graphical form. In all, 84 graphs and illustrations are included and methods of computation of surface area are put forward. Discussion. [P]

521. **Principles of Mineral Dressing.** GAUDIN, A. M. 1939, McGraw-Hill, London, pp. 554. Chapters 1 to 9 deal with the principles of crushing and grinding, size determination, machinery, classifier performance. Chapters 10 to 22 deal with the actual processing, giving examples from practice.

522. **Handbook of Mineral Dressing.** GERTH, HAMANN and SALZMANN. Bonn University Buchdruckerei Gebr. Scheur., 1952, 256 pp. 43.80 D.M.

523. **Chart for Crushing and Screening Problems.** GIBBS, R. *Chem. metall. Engng*, 1943, **50** (6), 134–5. For closed-circuit grinding systems comprising a screen and, e.g. a cone, jaw or gyratory crusher, a composite graph is given which enables the crusher load to be read directly if the screen efficiency, percentage oversize in feed, crusher opening, and percentage undersize from the crusher are known.

524. **Grinding Plant Research.** Parts 1–9. GILBERT, W. *Rock Prod.*, 1931–4, **34–7**. *See under* Ball Mills.

525. **Milling Machines and Material.** GROHN, H. *Farbenztg.*, 1930, **35**, 2328, 2376–424. Calculation of costs of milling from the use of sieves of varying mesh.

526. **Problems in the Reduction of Industrial Materials.** GRUNDER, W. *Verfahrenstechnik*, 1936, (1), 19–22. Since the knowledge of the physics of crushing is only at the beginning, further research into the theory and technology of this subject is necessary. In this paper a clarification is made of those factors which govern the treatment of a material in relation to its physical characteristics, and particularly the formation of new surface. Practical applications of present knowledge are suggested and reduction equipment is classified in relation to materials to be crushed or ground.

527. **Regulation of Particle Size in Flotation Product.** GRUNDER, W. *Verfahrenstechnik*, 1937, (3), 98–103. The advantage of sieving in conjunction with short tube mills is pointed out, especially if the grinding and sieving is done in stages by returning oversize. The cost of milling is smaller. Examples of flow sheets with graphical representation of results for several materials are given.

528. **Mechanization in Quarries.** HANDSCOMBE, J. P. *Quarry Mgrs' J.*, 1946, **29** (10), 494–521. A guide to mechanization in quarries, with some useful remarks on crushers and the relation of mechanization to the quality of product.

529. **Feed System in Grinding Mills.** HANNA, W. G., KAISER, H. E. and HARVEY, A.

U.S. Pat. 2318306, 1941. In a closed circuit, the oversize return is made to oppose by impingement, and control the amount of original feed.

530. **Control and Segregation in Dry Grinding.** HENDRYX, D. B. *Brick Clay Rec.*, Jan. 1954, **124**, 45–6. A discussion of the relative merits of jaw, gyratory and single roll crushers and of the merits of dry pan v. hammer mill grinding. The gyratory crusher has least upkeep cost, is expensive, but is best for abrasive materials and flat pieces. Heavy hammer or slugger mills produce a higher percentage of fines than double or single roll machines. Gyrasphere or else the short head cone cracks into grains or cubes with minimum of fines: no attrition action. Heavy smooth rolls as in mining industry give same results but wear more quickly with abrasives. Fine grinding—ball mills for abrasives: roller mills or impact mills for soft dry products. Merits of dry pan v. hammer. *See under* Hammer Mills.

531. **Factors Controlling the Capacity of Rock Crushers.** HERSHAM, E. A. *Trans. Amer. Inst. min. (metall.) Engrs*, 1923, **58**, 463–78. Experiments made on a crusher to determine a factor to apply to theoretical capacity are given for various conditions of operation and for different ores.

532. **The Mechanics of Pulverizers.** HEYWOOD, H. *Chemical Engineering Practice*, Vol. 3, Chap. 4, pp. 97–108. Butterworths Scientific Publications, 1957. The relationships between power, throughput and fineness of product are discussed and presented in graphical form. Sections on the dynamics of ball mills follow. 6 refs.

533. **Crushing Iron Ore.** HOWAT, D. D. *Iron Coal Tr. Rev.*, 1948, **157**, 23 July, 177–183; 30 July, 239–44.

Pt. 1. Theoretical Considerations. The article deals with the basic considerations underlying present-day crushing techniques, including discussions on the relation between useful work and size reduction, fracture characteristics, particle sizes and characteristics and their influence on crusher design.

Pt. 2. Practical Aspects. Discussion of the various types of crushing machine used in industry, including jaw, gyratory, coarse roll, cone and hammer crushers, with features of each compared. A grizzly is illustrated and described. The advantages of non-choking curved plates of jaw and gyratory crushers are discussed, particularly with regard to output. The merits of multi-stage crushing are discussed. Illustrated. 6 refs.

534. **Factors which Influence Variations in Grinding and Screening.** HURSCH, R. K. *Brick.*, 1937, **91**, 133. Grinding is influenced by the size, moisture content, hardness and cleavage of the material, and by the type of grinder, maximum size of discharged particles, rate of feed, and type of screen. These factors are briefly discussed.

535. **Preparation for Mining Raw Materials.** KIRCHBERG, H. 1953, W. Gronau, Jena. 236 pp. 19 DM. Review in *Glückauf.*, 1954, **90**, 627. Pt. 1. General preparation, processes and machines (including coal). *Fuel Abstr.*, 4302, Nov. 1954.

536. **Progressive and Controlled Grinding.** LABAT, M. *Génie Chimique*, July 1956, **76** (1), 1–11. After a review of the theoretical considerations and the data associated with change in size and distribution during normal grinding practice, the author points out the advantages to be derived from a procedure which he describes as progressive and controlled reduction. The paper refers chiefly to reduction to say—3 mm to carr or hammer mills. The procedure is that of interposing a sieve in a closed circuit, and a complete quantitative analysis of the circuit is made and illustrated by a series of graphs. Also taken into consideration are the effects of hardness of material (coking coal in this paper), wear on hammers and its quantitative effect on the product, moisture content, the effect of warming the sieve on the ease of sieving, and therefore on the dimensions of the sieve and the beneficial effect of partly dried oversize return on the feed moisture content. Other economies are indicated.

537. **Fine Grinding Investigations at Lake Shore Mines.** LAKE SHORE MINES STAFF.

Trans. Canad. Min. Inst. (*Inst. Min. Metall.*), 1940, **43**, 299–434. A report on seven years' experimental 'fact-finding' investigations into fine grinding of Lake Shore ores, with major emphasis on tube milling. *See* Nos. 1067 and 1119. [P]

538. **Chemical Engineering Techniques.** LANER, E. E. and HECKMAN, R. F. Reinhold Publishing Corporation, 1952. Chap. 4, Size Reduction, pp. 119–38. The principles of the chief types of equipment are described, including a small section on liquid reduction. The difficulties and chief methods of reducing fibrous materials are also discussed. Chap. 5, Size Classification. The techniques of classification are described, including those known as gravity separation.

539. **Economics of Stone and Coal Crushing. Principles of Various Units.** MACCARTHY, C. P. *Iron Coal Tr. Rev.*, 1953, **167**, 1457–60.

540. **Crushing Practice and Theory.** MCGREW, B. *Rock Prod.*, **53, 54, 55, 56**; Abstract in *TonindustrZtg*. 1953, **77** (1/2).

Pt. 1 June, 1950, 118–20.	Historical summary, from 1830.
Pt. 2, Sept. 1950, 95	Definitions used in crusher operations. Operating terms and crusher classification.
Pt. 3, Oct. 1950, 116–7	Operating characteristics of various types of crusher. Gyratory crushers.
Pt. 4, Nov. 1950, 62–3.	Gyratory crusher concaves. Description and tabulated settings.
Pt. 5, Dec. 1950, 128–9.	Gyratory reduction crushers. Reversible concaves. Fine reduction crushers. Hydrocone crusher.
Pt. 6, Feb. 1951, 106–8.	Some factors which influence crusher performance. High- and low-speed products. Reduction ratio and feed effects.
Pt. 7, June 1951, 118–21.	Jaw crushers, types and special uses. Geometrical analyses, tabulated settings. Diagrams.
Pt. 8, July 1951, 65–8.	Crushing rolls and their use. Includes chart for speed, diameter, and feed size.
Pt. 9, Aug. 1951, 164–8.	Special types of roll crushers, including toothed roll crushers.
Pt. 10, Sept. 1951, 67–9.	Characteristics and performance of hammer-mills. (Includes diagram of one hammer-mill with five stages of rebound from an involute casing.
Pt. 11, Oct. 1952, 107–9.	*P* crusher product curves and tables. Performance data for primary crusher products are presented graphically.
Pt. 12, Nov. 1952, 79–81.	Selecting primary crusher. Consideration of project involved.
Pt. 13, Dec. 1952, 91–3.	Selection of quarry equipment for efficient crushing practice. A table of suggested sizes is included.
Pt. 14, Mar. 1953, 105.	Comparison of gyratory and jaw crushers as primaries.
Pt. 15, May 1953, 96–102.	Selection of secondary reduction crushers.
Pt. 16, June 1953, 128–32.	Crusher operation in open and closed circuit compared. Advantages of surge bins and storage piles.

541. **Handbuch der Staubtechnik** (Handbook of Dust Technology). MELDAU, R. Verein Deutsche Ingenieur Verlag, Düsseldorf, 1952, 254 pp., 155 illustrations, 21 tables, 24 DM. *See under* Dust Hazards.

542. **The Incidence of Wear in Crushing and Grinding Machines.** MITTAG, C. *Verfahrenstechnik*, 1939, (2), 60–2. It is intended to make clear the influence of friction and wear on the wasted energy and on the output of various machines as well as its relation to the type of machine. The 'Concentra' tube (ball) mill is designed, for instance, to minimize friction.

543. **Die Hartzerkleinerung (1867–1949).** (Crushing and Grinding.) MITTAG, C.

1953, Springer-Verlag, Berlin, 372 pp., 190 figs., 90 refs. Pt. 1. Size reduction and machines. The machines for coarse and fine grinding are described and well illustrated. Grinding and drying, and the modern vibratory ball mill are included, pp. 1–174. Pt. 2. Underlying theory and its practical application. Certain techniques are dealt with specially; e.g. explosion, vibratory ball mill and prall mill techniques, pp. 175–250. Pt. 3. Application in industry, including classification, pp. 251–335.

·544. **Grinding Crystalline Material.** MOND, A. L. *Engl. Pat.* 272109, 1926. Bulk density is increased by grinding under pressure, e.g. in an edge runner mill, so as to destroy hollow spaces produced in the powder granule by pseudomorphosis in the manufacture.

545. **Results of Grinding Investigations Carried Out at the Mineral Dressing Laboratory.** MURKES, J. (Inst. of Mineral Dressing, Royal Inst. of Technology, Stockholm). *O.E.E.C. Technical Assistance Mission*, No. 127, 1953, O.E.E.C., Paris, 9 pp. Obtainable from H.M. Stationery Office. Some new views and methods of interpretation. The author seeks to define some of the objects of grinding and the significance of some of the criteria. The advantages of using small balls for grinding are given, and of rod-mill grinding are assessed, but the lack of sufficient experimental background has yet to be remedied. Graphic representation of results of experiments which show the advantages of using small balls for fine products are presented. These refer to suitability for dressing of the product, energy consumption and grain size distribution. Much more investigation is needed before a quantitative relationship between the variables can be established. The use of the rod mill at certain stages of grinding is advocated. [P]

546. **Contamination of Rock Samples during Grinding as Determined Spectrographically.** MYERS, A. T. and BARNETT, P. R. *Amer. J. Sci.*, 1953, **251** (11), 814–32; *J. Amer. ceramic Soc.*, 1955, **38** (5). The kind and degree of contamination resulting from pulverizing in heavy grinding machinery is studied for six hard rocks, six unconsolidated sediments, one massive quartz and one quartzite. The contamination found was as high as Fe—1·5, Ni—0·006, Mo—0·002, Cr—0·001, Co—0·002, V—0·001, Cu—0·003, Mn—0·1, per cent respectively. 5 refs.

547. **A Symposium on Milling Devices and Practices.** MYERS, J. F. and TOWER, R. J. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 2162, May 1947. Dealing with mineral dressing, and the equipment used, the authors describe and illustrate methods of storage, conveyors, chutes, screens, classifiers, filters, and auxiliary equipment such as pumps, pipe lines, pulp distributors. Reference is made to stroboscopic viewing of grinding carried out on a small ball mill and the differential movement of different layers of balls observed. 15 pp., 14 figs., 22 refs.

548. **Zerkleinerungs Vorrichtung und Mahl-anlagung.** (Crushing and Grinding Equipment.) NASKE, C. 1921, Verlag Otto Spamer, Leipzig. 330 pp., 415 figs. The book is devoted to a description of reduction and ancillary equipment, preceded by five pages of discussion on energy considerations and the application of the Rittinger hypothesis. Includes a chapter on stamp mills.

549. **Factors Governing Particle Size Grading of Pulverized Materials.** NORTH, R. *Industr. Chem. Mfr.*, 1948, 24 (276), 5–11.

550. **Grinding Practice as Related to the Characteristics of Materials to be Pulverized.** NORTH, R. *Trans. Instn chem. Engrs, Lond.*, 1954, 32 (1), 54–60. The characteristic properties of materials are enumerated and their effects on equipment design pointed out.

(1) *Hardness.* Effect on output. Superfine product decreases with increasing hardness.

(2) *Toughness* (e.g. rubber, ebonite, perspex). Difficult to grind, but freezing facilitates and is sometimes the only way (e.g. nylon). Expensive, but justified from fire risk, preservation of flavour, vitamins.

(3) *Abrasiveness.* Wear. Generally No. 4 Mohs' scale are abrasive. Over No. 5, cost of wear in hammer mills is prohibitive, e.g. pyrites, coke, quartz and silica sand. Better in ball mills where balls can be replaced cheaply.

(4) *Stickiness.* Causes overload by adhering to the walls and falling. Agglomeration and poor classification and large circulating load. Best to dry completely if suitable, or put in hot air. Vibration avoids accumulation of heavy cake. Introduce, say, kaolin to improve flow properties, or certain additives to prevent agglomeration. Ball mills and screen-type hammer mills are unsuitable.

(5) *Temperature.* Cool air or refrigerated air. But this increases size of dust collector.

(6) *Structure and Shape.* The difference between friability with 'fines' range and other materials with large fragments. Flaky particles are more difficult to grind and to classify. Output is diminished by flaky material. Roller and ball mills much more suitable than hammer mills. *Fibrous* materials are best dealt with in special forms of hammer mills which are used as shredders.

(7) *Specific Gravity.* Output by weight is proportional.

(8) *Free Moisture Content.* Damp materials can be dried for dry grinding or wetted for wet grinding. Otherwise they cake. One per cent moisture is about the limit, but probably less for a heavy material such as barytes, and much less according to the fineness of grinding required, 0·2% for very fine grinding. Hot air used sometimes. But material should be dry before *crushing*. Hot air carrying superfine dust particles must have a totally enclosed dust collecting system, which is expensive, and it may be cheaper to put in a pre-drying plant.

(9) *Stability.* Inert gas or flue gas. 8% CO_2 gives protection for sulphur. Flue gas cheapest, but a dust collector is necessary. Explosion vents are advisable. Blast walls. Light roof. H.M. Inspector of Factories has a list of tested materials to be ground and advises on precautions. Starch, sugar, sulphur, pyrites, metal powders. Materials with water of crystallization need cold air.

(10) *Homogeneity.* With non-homogeneous materials, e.g. softer material+0·5% quartz grains, the latter accumulates to a high percentage of the charge being actually ground and can cause serious wear, especially in high-speed mills, unless specially discharged. With recirculation the whole system can become overcharged. Therefore impact must be retarded and consequently output. The remedy is a separate mill to regrind the rejects. Ball and pebble mills are the most suitable, not high-speed mills. The only adverse effect here is reduction of output.

(11) *Physiological Effect.* Remedies: wet grinding or efficient collection of dust under suction. Feed precautions. Avoidance of dusty elevators and poor sacking methods.

(12) *Purity.* Regarding permissible contamination with iron or silica and elimination chemically or magnetically (for iron). Stainless steel construction.

(13) *Size of Feed.* For milling, hard feed should be precrushed to less than ⅜ in., soft feed could be up to 1½ in. Feed that is too large could accumulate in the grinding chamber.

(14) *Fineness of Product.* Most powders tend to blind screen cloths finer than 60 mesh. Therefore air separation is generally the best. Fine screen cloths are expensive to buy and maintain. Punctures may pass undetected. Sizing 10-mesh product can be done by air, but is expensive in fan power. Change over from screen to air classification becomes advisable at about 30 mesh.

Summary. 1 ref.

551. **The Present State of Grinding Technology.** QUESNEL, G. (Société Stein et Roubaix Paris.) *Génie Civ.*, 1953, (19), 370–1; (2)0, 388–90; (21), 405–6. The three articles review the present state of pulverizing technique. They deal respectively with the characteristics of the material to be ground and methods for determination; the second deals with the three mechanisms of grinding and the appropriate equipment: (1) by reducing between a moving and a stationary surface; (2) by impact or shock; (3) by trituration as in a ball mill. Some equipment is illustrated. The third article

deals with methods of separation, simultaneous drying and grinding, choice of type of grinder, wet grinding and method of feed.

552. **The Mineral Dressing Laboratory at Atomic Energy Research Establishment, Harwell.** PATCHING, S. W. F. *Industr. Chem. Mfr.*, Feb. 1952, 65–71.

553. **Comminution Plant.** PIONEER ENGINEERING WORKS, Minneapolis. *Engng News Rec.*, 1951, **146** (2), 135. A booklet giving information on crushing, screening and washing, and material handling. Charts are presented showing the percentage of each size of stone to be expected in the produce of crushers.

554. **A Discussion of Grinding and Classification Circuits.** PLAYFORD, M. E. *Proc. Amer. Inst. Min. Engrs* (New Series), 30 Sept. 1933 (91), 439.

555. **Mineral Dressing at the Royal School of Mines.** PRYOR, E. J. *Nature, Lond.*, 1954, **173** (4404), 565–6. The resources of the new laboratories opened on 17 March 1954 and their applicability to special training in this subject.

556. **Particle Size Analysis of Crushed Products.** RATCLIFFE, A. *Proc. Instn mech. Engrs, Lond.*, 1950, **162**, 378–91. The differences in size reduction produced by a hammer mill, a ball mill and jaw, gyratory and roll crushers have been examined by sieve analyses. The products of the mills contain a larger ratio of small sizes; the crushers produce a closer grading of the coarse particle fraction owing to their sizing action. Gaudin's law of particle size distribution is given a mathematical basis.

557. **Textbook of Ore Dressing.** RICHARDS, R. H. and LOCKE, C. E. 1940, 3rd Edn., McGraw-Hill Co., New York. Laws of crushing, chap. 7, pp. 88–94. Discusses Rittinger and Kick laws. Gives formula for the calculation of horsepower in crushing. Concludes that friction plays a large part in crushing; external (among the fragments) and internal (molecular). Classifying and settling in water, chap. 10, pp. 127–70. Gives laws of settling and the results of experiments. Describes several classifiers. (2nd Edn. 1925, 1st Edn. 1903.)

558. **Cast Iron for Crushing Machinery.** RILEY, R. V. *Int. chem. Engng*, 1950, **31** (4), 170–3; (11), 500–2. An outline of the qualities required in an abrasion-resistant casting, and a review of the metallurgical properties of some cast irons. A review of recent improvements in crushing and grinding machinery.

559. **Size Reduction.** RILEY, R. V. *Int. chem. Engng*, 1950, **31** (1), 15; (4), 170–3; 1951, **32** (1), 22–6; (12), 577–81. A review covering jet mills, homogenizers, particle size measurement, explosion, fire risks, and recent improvements in crushing and grinding machinery. 63 refs. Jet pulverizers open up new possibilities; and 100% agreement with practice is claimed for one theory of the ball mill.

560. **Size Reduction.** RILEY, R. V. *Chem. and Process Engng*, 1953, **34** (1), 8–12. A survey of 1952 papers. Grinding theory. F. C. Bond's, Carey & Stairmand's theories. Operational principles are dealt with in detail. New research and studies in 1952, including the Cremer Committee needs. New materials for machinery and a tabular representation of wear-resisting alloys. Review of crushers and of ball mills and jet pulverizers. Specialized methods, e.g. micronizers and pan mills. 50 refs.

561. **Size Reduction.** RILEY, R. V. *Chem. and Process Engng*, 1954, **35** (3), 81–4. A survey of the literature 1952–3. The flow diagram for preparation of vermiculite is included. 77 refs. *See also Vermiculite*, H.M. Stationery Office.

562. **Size Reduction.** RILEY, R. V. *Chem. and Process Engng*, 1955, **36** (6), 199–202. A review of developments during 1954 as reflected in periodical and patent literature. Concludes that little contribution is made to the understanding of the fundamentals of comminution, although scientific approach is applied to practical problems.

563. **Standardizing Rock-Crushing Tests.** RODGERS, M. K. *Bull. Amer. Inst. Min. Engrs*, 1915 (105), 2053. Reports of rock-crushing tests should include the following details: (1) Description of the machine employed (jaw or gyratory crushers, rolls,

stamps, tubes mills, Chilian mills, etc.). (2) Method and material (timber, concrete, etc.) of foundation. Much power is dissipated in the vibration of poor foundations. (3) Locality from which the rock or ore was obtained, and geological, mineralogical, and physical characters of the material. (4) The power consumption of the machine running with no load and with full load, the unit of power being 1 h.p. per 24 hours. (5) The capacity of the machine in tons (of 2000 lb) per 24 hours. (6) The duty in tons per horsepower-day. (7) The screen analysis of feed and product by the proposed A.I.M.E. standard screen scale.

564. **Researches on Stone Crushing with Particular Regard to the Shape of the Product.** ROSSLEIN, D. *Quarry Mgrs' J.*, 1946, **30** (4), 207–22; *Build. Sci. Abstr.*, 1946, **19**, 353. *See under* Aggregate.

565. *Developments in Size Reduction Technique.* RUMPF, H. *Chem. Fabr.*, 1953, **5** (7), 521–6. A vital factor in development is a clarification of the objective in any crushing problem, e.g. specification of requirements for fineness, upper and lower limits, shape and size distribution of particles, the precise effects on these of the crushing devices in relation to the properties of the feed material. A comprehensive table is presented, showing the relation between the characteristics of some 30 types of material, their uses, and the particle characteristics of the ground product. In addition, the individual methods of size reduction are treated briefly with regard to modern development.

The paper is not concerned with coarse crushing.

566. **Simultaneous Grinding and Flotation.** SCHELLINGER, A. K., SHEPARD, O. C. *Min. Tech.*, Sept. 1948, **12**, *Tech. Ppr*, No. 2461, 6 pp. A laboratory grind float machine is described. Tests on two different ores show that overgrinding is lessened by combining flotation–separation with grinding into one operation. *See under* Ores.

567. **The Effect of the Solid-liquid Ratio on Grinding a Ceramic Nonplastic.** SCHWARZWALDER, K. and HEROLD, P. G. *J. Amer. ceramic Soc.*, 1935, **18**, 350. An electric-furnace mullite, previously ground to pass an 8-mesh screen and of sp. gr. 3·04, was wet-ground with solid–liquid ratios of 2·7 to 1 and 1 to 1·5 for various lengths of time. Grain-size distribution and surface area, determined by the Wagner turbidometer method, were compared. The material ground with the least water gave a lower percentage retained on a 325-mesh screen, fewer particles between 10 and 60 microns, and more between 0 and 10 microns.

568. **Fine Grinding of Minerals.** SHAY, F. B. *Foote Prints rare Met.*, 1941, **14** (2), 1. The variation of certain properties with particle size is indicated, and the relation of power input to particle size is shown. The different types of classifiers used for the wet and dry separation of the ground materials are reviewed, and a general description is given of the methods of checking the size of the products.

569. **Primary Crushing. (Progress Report No. 2.)** SHEPPARD, M. *Rep. Invest. U.S. Bur. Min.*, No. 3380, 1938, 16 pp. An investigation on the lines of Report No. 3377 with a 60×48-in. Blake *jaw* crusher and 27-in. *gyratory* crusher, crushing granite. 12 graphs and 8 tables are presented. Among a list of conclusions concerning particle distribution of product, it is suggested that particle shape is a function of reduction ratio rather than crusher setting, the smaller the ratio, the more nearly cubical the product so far as the above two crushers are concerned. [P]

570. **Primary Crushing. (Progress Report No. 3.)** SHEPPARD, M. *Rep. Invest. U.S. Bur. Min.*, No. 3390, 1938, 10 pp. Reports 3377 and 3380 dealt with comparisons of different types of crushers crushing the same type of stone. The present deals with the relation between feed and product of two different limestones as to size distribution and shape, when crushed in the same crusher, a 48×36-in. Blake-type *jaw* crusher. 11 graphs, 6 tables. The results show that there is no relation between the size distribution curve and the shape of the product, and suggest as in No. 3380 that the major tendency of crushers that depend on pressure for comminution is to break through

the particle in a direction normal to the crusher faces, forming nearly cubical fragments, and that the minor tendency is to break by radial pressure to form slabs. The tendency to formation of cubes is particularly noticeable in crushing $-12+8\cdot5$-in. lumps, the most cubical size product being $-8\cdot5+6$ in. (the product of a single break). [P]

571. **Primary Crushing.** (**Summary of Field Tests.**) SHEPPARD, M. *Rep. Invest. U.S. Bur. Min.*, No. 3432, 1939, 41 pp., 5 figs., 31 tables. The investigation is concerned with the relationship between the size distribution of the feed to and the product from primary crushers and with effect of crushing on the shape of the products under various conditions. Brief mention is made of the different types of primary crushers in use, and descriptions are given of the method of selecting samples and of determining size distribution. The results of tests made in different crushers are tabulated and the conclusions drawn are as follows: (1) the size distribution of the products from crushing, under similar conditions of feed and discharge setting, in the Blake-type crusher, the gyratory crusher, and the single roll crusher is similar; (2) changes in the size distribution of the feed to the crusher are reflected to some extent in the size distribution of the products; (3) crushing a selected size of small lump stone produces a higher percentage of coarse product in the sizes near that of the crusher discharge than the crushing of large lump stone; (4) crushing run-of-quarry stone produces more fines than the crushing of lump stone; (5) the size distribution of the product from crushing in the swing-hammer mill differs greatly from that of other crushers used; (6) changes in the size distribution of the feed to the swing-hammer crusher cause no change in the size distribution of the product; (7) changing the size of the discharge opening of Blake-type crushers causes changes in the size of the product; (8) the effect of scalping from the crusher feed the material smaller than the crusher discharge opening and recombining the scalped material with the crusher product is to reduce the amount of fines produced, irrespective of the friability of the stone crushed. [P]

572. **Size Reduction.** SMITH, JULIAN C. *Chem. Engng*, Aug. 1952, 151–66. An up-to-date presentation of the field of size reduction (previous special issue on Mechanics, see *Chem. Processing*, 1938). Emphasis on the selection of crushing and grinding equipment. A list of 37 firms and addresses and types of equipment made. New techniques. Descriptions of various types, with illustrations and with curves showing relations between capacity, size and horsepower, etc., in many cases. General theory, brief discussion. [P]

573. **Pulverizer Performance.** SMITH, V. *Elect. Rev., Lond.*, 8 Oct. 1948, 553–5. Comparison of three types of mill. The low-speed ball mill, the medium-speed vertical ball or roller mill, and the high-speed horizontal axis beater mill are considered from the points of view of first cost, effects of moisture content, manufacturers' guarantees, maintenance costs, annual charges, power consumption, fuel costs and efficiencies. Taking these together the low-speed mill in spite of higher initial cost and power charges shows a substantial annual saving over the medium and high-speed mills, by a small fraction of the fuel and power costs. [P]

574. **Notes on the Selection of Pulverizers.** SMITH, V. *Cheap Steam*, 1950, **34**, 107–9. Gives a list of the factors governing the choice of a pulverizer (for coal) and discusses each factor. Graphical representation of the effects of grindability, fineness of product, moisture content.

575. **Handbook of Ore Dressing.** TAGGART, A. F. 1927, Wiley & Sons, New York; Chapman & Hall, London. Rewritten as: *Handbook of Mineral Dressing*, 1945, 22 sections, 1900 pp. The book deals with the mechanical processes involved in the concentration of metalliferous ores and the beneficiation of industrial minerals. It is based on replies to elaborate questionnaires. Consequently in the sections dealing in detail with milling and crushing machinery, extensive tabulation of performance data is presented. [P]

576. **New Units of Crusher Capacity and Crusher Efficiency.** TAGGART, A. F. *Tech.*

Publ. Amer. Inst. Min. Engrs, No. 1297; *Amer. Ceram. Abstr.*, **20**, 268, 1941. The capacity of a crusher depends on the crusher setting size of feed, fines, moisture, and method of feeding. This is expressed by $T_R = T_{R80}KK'K''$. T_R, reduction tons per hour, is the new capacity unit. T is hourly weight of feed coarser than the coarsest discharge. R_{80} is 80% reduction ratio and is the aperture that would pass 80% of the feed divided by the aperture passing 80% of the product. K, K' and K'' are kind of rock, moisture and method of feeding respectively. R_{80} may be estimated from tables given if it cannot be measured. K is 1·0 for limestone, 0·85 for granite, and 0·75 for trap or diabase. K' is 1·0 but may fall to 0·5 or less if the fines are wet enough to cake. K'' averages 0·5 and rarely exceeds 0·75. The efficiency unit proposed is reduction tons per horsepower-hour and is $E_c = T_R/P$. P is horsepower consumed. E_c is fairly constant for one crusher. Examples are given for the calculation and use of E_c.

577. **Crushing and Grinding.** Ure, S. G. *J. Soc. chem. Ind., Lond.*, Pt. I, 1924, **43** (2), 1144; Pts. II and III, 1925, **44**, 321, 349, 551. Current types of grinding equipment are described and illustrated. Part I. A short discussion of the principles of comminution and of Rittinger and Kick laws precedes a description of jaw, gyratory and disc crushers. Part II. Deals with breaker rolls, four-roll crushers, three-tier breakers, impact (hammer) mills. Disintegrators, opposed hammer mills, pin mills, horizontal and vertical, squirrel-cage mills. Part III. Deals with ball mills, Allen's 'Stag' ball mill, Hardinge mill, tube mills, combined gyratory and cone crusher, Griffin mill, Bradley three-roll mill, ring-roll mill (vertical ring), Huntington mill (horizontal ring and runners), Raymond mill, Fuller mill (ball race).

578. **Progress in the Field of Heavy Chemical Equipment.** Waeser, B. *Chem. Fabr.*, 1941, **14**, 39; *Ceramic Abstr.*, 1942, **21**, 219. A discussion of the factors promoting efficiency in grinding, followed by a review of new construction and patents. 60 literature refs. 50 German patent refs., from 1928 onwards.

579. **Milling.** Waeser, B. *Kolloidzschr.*, 1952, **126**, 149–50. A review of recent developments in crushing and grinding, beginning with a discussion of various theoretical treatments, e.g. Smekal, Pelshenki, Anselm.

The achievements of jet mills are then referred to with the achieved finenesses of some 17 minerals. Reduction of food materials is then discussed and two pages are devoted to a review of a large number of German patents. A final section describes some new construction developments and over 40 refs. are appended.

580. **Grinding Plants for the Cement Industry.** Walder, E. *Escher Wyss News*, 1950–51, 23/24, p. 102. A description of combined drying and milling with pneumatic classification, followed by a description of a mechanical classifier which is claimed to save 15% of power consumption if used instead of pneumatic classifier.

581. **Crushing and Grinding.** Principles of Chemical Engineering, Chap. 9. Walker, W. H., Lewis, W. K., Gilliland, E. R. and McAdams, F. 1937, McGraw-Hill Co. 749 pp. Particle size. Energy consumption. Kick v. Rittinger laws. Selection and classification of machines. Primary and secondary crushers (Intermediate). Pulverizers. Conditions governing fineness. Description of mills.

582. **Crushing and Grinding Techniques.** Walter, J. *Rev. Matér. Constr.*, 1952 (441), 163–70; (442), 193–98. This is a study of recent English technica literature. It notes the considerable progress brought about by large-scale tests in U.S.A., Canada and South Africa. The French technician has at his disposal the experience of foreign research workers, who are less concerned with formulating laws than with ascertaining the best industrial conditions. The paper reviews the advantages of the various kinds of crushing operation, while advocating continuous cycle and multi-stage operations. A large bibliography is appended, 20 annotated refs. and 38 others.

583. **Interpretation of Sieve Analysis.** Warneke, F. *Chem. Engng Min. Rev.*, 1946, **38** (453), 323–9. The author discusses a method for calculating the efficiency of size

reduction processes based on a knowledge of size distribution. Although sieve analyses of heterogeneous materials cannot be extended mathematically as the author has done with fairly homogeneous materials, it is obvious that the large surface area associated with the finest size particles indicates a large proportion of energy wasted on unwanted fines. Even a small reduction of this fines would allow more energy for useful grinding and would repay efforts in design for such economy.

584. **Crushing and Pulverization.** WORK, L. T. *Industr. Engng Chem.* (*Industr.*), 1929, 21, 498. Reference is made to the low apparent efficiency of crushing and grinding and to Martin's and Gaudin's equations for the size distribution of particles. The author suggests that Martin's law holds for the larger size of particle and is a primary function, and that to this primary function is added a secondary function. The remainder of the paper describes various types of crushing and grinding mills.

585. **Developments in Grinding.** WORK, L. T. *Industr. Engng Chem.* (*Industr.*), 1938, **30**, 130–5. The author mentions modifications in gyratory crushers to overcome difficulties in finer grinding, also the Simons disc crusher, roll granulator, the Raymond bowl mill and its advantages, the new Babcock & Wilcox ball and ring mill and its characteristics, new high-speed mill designs, and a concentric basket mill. Modifications in ball-mill liner design and material, the novel German vibration ball mill and the renewed status of fluid jet mills are discussed. Grinding aids, plant auxiliaries are referred to. Diagrams include particularly those of liner plates of ball mills and high and low outlets of the latter. 3 refs.

586. **Size Reduction. Crushing and Grinding.** WORK, L. T. *Industr. Engng Chem.* (*Industr.*). This is one of the Unit Operations section of each January issue of 'I.E.C.' from 1947, **39**, to 1953, **45**. Since then the Unit Operations review section has appeared in the March issues.

A summary is presented of the published papers of each preceding year on grinding mills, particle size measurement and classification.

GRINDING AND DRYING

587. **Lurgi Mahltrocknungs Process (Pulvo-Drying).** O.T.S. U.S. Dept. Commerce, PB. 22497, 72 pp. A process developed jointly by Krupps and the Lurgi Gesellschaft für Warmetechnik, for drying and disintegrating, in suspension, high-water-content coal of the lignite type. Full details are given, supported by illustrations. The process has some real merit, but appears somewhat complicated.

588. **Experience with the Combined Drying and Grinding of Clay.** BALKEVICH, V. L., DOBROVOLSKY, I. S., ZAYOUTS, R. M. *Glass & Ceramics, Moscow* (*Steklo i Keram*), 1951, **8** (2), 12. *Trans. Brit. Ceram. Soc.*, 1951, **50** (9), 377a. A Russian institute has built and tried out an installation for the simultaneous grinding and drying of clay.

589. **Simultaneous Grinding and Drying of Clay.** BUTKEVICH, V. M. *Glass & Ceramics, Moscow* (*Steklo i Keram.*), 1952, 9 (10), 14–7. Translation by Cass in *Brit. Clayw.*, Aug. 1953, **62** (736), 154. An air-swept hammer mill was used. Results were quite satisfactory. There was no clogging. Performance and results from several tests are tabulated.

590. **The Simultaneous Grinding and Drying of Clay.** ESSERE, G. *Industrie céramique*, 1952 (433), 257–8. *See under* Ceramics.

591. **Mill Drying of Coal.** FITZE, M. E. *Trans. Amer. Soc. mech. Engrs.*, May 1941, **63**, 273–6. Mill drying by means of flue gases is shown to result in improved efficiency, less deposit, reduced capital outlay and costs, and the practical elimination of fire and explosion hazards.

592. **The Combined Drying and Grinding of Clay in a Shaft Mill.** GONCHAR, P. D. *Glass & Ceramics, Moscow* (*Steklo i Keram.*), 1951, **8** (2), 16–18. The dimensions of a shaft hammer mill for grinding plaster were too large and the rotation speed too low

for the combined grinding and drying of clay. A smaller mill would permit smaller volumes of gas at high temperature to pass at high speed and carry 2- to 3-mm particles.

593. **The Mill Unit as a High-duty Dryer.** HANDSCOMBE, F. L. and MOYER, J. Proceedings of the Pulverized Fuel Conference, Institute of Fuel, London, 1947, 747–67. Greater efficiency can be obtained and the cost of equipment reduced by drying and milling coal in a single operation. The drying capacity of a mill is calculated and the combined mill performance is presented graphically, showing where grinding capacity exceeds drying capacity and vice versa. The paper concludes with an account of features of mechanical design which must be considered in avoiding operating troubles. [P]

594. **Mechanics of Present Pulverizing Practice.** HAWKSLEY, P. G. W. Proceedings of the Pulverized Fuel Conference, 1947, 656–87. Institute of Fuel, London. Includes performance data on grinding and drying. An approximate calculation of the drying capacity of pulverizers is given in a short appendix. [P]

595. **A New Method of Drying and Grinding Clays.** MAHLER, J. H. *Claycraft*, 1951, **24** (1), 249–52. A disintegrator is described which is swept with hot gases so that moist ball clay containing 16% water can be crushed to a dry powder having only 1% water of which 90% will pass a 300-mesh sieve. The machine is self-contained and consists of firstly a hammer mill for beating the clay against the liner, after which the reduced material is further reduced by air turbulence in an attrition zone. Hot gases from a coke, coal or oil furnace are delivered via a cyclone to the mill unit. Nine tons per hour of coarsely-ground clay are obtained from 70 h.p. Illustrations.

596. **Quantitative Data on Mill Drying.** NASKE, C. *Zement*, 1933, **22**, 719–22. Data in detail are given for a Humboldt Mill and two Loesche Mills. Other mills suitable for this work are illustrated diagrammatically. 7 refs. [P]

597. **Graduated Process of Drying, Crushing and Grinding Clay.** OTTO, C., G.m.b.H. *Chem. Tech., Berlin*, 1942, **15**, 185; *Build. Sci. Abstr.*, 1943, **16**, 18. Crushing and grinding are carried out in three stages, as high as possible a moisture content being maintained. Only sufficient hot air is introduced during the second stage of crushing and during grinding in order to prevent the clay sticking during the latter process.

598. **Mill Drying in Pulverizing High Moisture Coals.** ROGERS, W. C. *Mech. Engng, N.Y.*, 1953, **75**, 659–70. At above 8–10% moisture, handling is difficult. The paper describes the conditions for satisfactory mill drying and suggests measures for treating wet coal where increased drying capacity is not desired. For instance, greater turbulence and higher temperature of the drying air are suggested. A flow sheet and a diagram of a swing-hammer crusher dryer with feeder are given.

599. **Mill Drying.** ROSIN, P. and RAMMLER, E. *Ber. Reichskohlenrates*, No. 10; *Braunkohle*, 1927, **26**, 261, 286. Ring-roll mill performance on coal with simultaneous drying and grinding. Heat requirements and the necessary compromise between grinding and drying are dealt with. [P]

600. **Flash-Drying and Calcining as Developed from Mill Drying.** SENSEMAN, W. B. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1897, 1945, 13 pp.; *Min. Tech.*, 1945, **9** (5). All grinding plant using air removal has tended to dry the material being ground. This has now been developed to a process in which drying and/or calcining is the main object. High-speed hammer or squirrel-cage mills are used, with fan combined and a cyclone separator working on a closed air cycle. From this a venting fan draws off moist air, which is replaced by hot gases from a furnace. Very wet feed, containing 60% of H_2O, can be mixed with pre-dried material before passing to the mill, whilst multi-stage working makes for thermal economy and high temperature, if required, in the final stage. Short heating periods and rapid cooling of hot gases makes the process workable with heat-sensitive substances. 10 diagrams.

601. **New Ways for Drying, Milling and Dust Removal.** TIVES, T. H. *Ber. dtsch keram. Ges.*, 1938, **19**, 85. A description with diagrams of grinding coupled with pneumatic drying and classification. Various types of mill are described.

602. **Grinding Plants for the Cement Industry.** WALDER, E. *Escher Wyss News*, 1950–51 (23/24), 102. A description of combined drying and milling with pneumatic classification.

SUPERFINE GRINDING

603. **Grinding and Treatment of Minerals.** *B.I.O.S. Final Report*, No. 1356, p. 32. H.M. Stationery Office. A Vibration ball mill made by Siebtechnik G.m.b.H. can reduce hard materials down to 1 micron. *See under* Vibratory Ball Mills.

604. **Fine Grinding in Oscillating Ball Mills.** *See also under* Vibratory Ball Mills.

605. **Some Experiments on Colloidal Grinding with a Ball Mill.** ANDREASEN, A. H. M., BERG, S. and KISER, E. *Kolloidzschr.*, 1938, **82**, 37–42. A reduction to less than 100 milli-mu was accomplished by grinding (for the first time) in a laboratory mill. Finely-ground iron oxide or barytes in quantities of 1500 g was ground with 7·94-mm or 3·93-mm steel balls, using 1500 c.c. water with sufficient sodium pyrophosphate to achieve a 0·01 molar solution. This was to reduce viscosity as grinding proceeded. Further additions of pyrophosphate solution became necessary to maintain a low viscosity. Samples were withdrawn by pipette at intervals during a 72-hour grinding, and after certain precautions, the size distribution was determined by the Andreasen pipette method. The course of the reduction is tabulated. Approximately 50% of the barytes charge was reduced to colloidal dimensions (100 milli-mu) in 72 hours. Refs. quoted: Ultino, B., *Kolloidzschr.*, 1923, **32**, 149; Berg and Reitstatter, *ibid.*, 1928, **46**, 53; Kiesskalt, *Verfahrenstechnik*, 1936, (3); Naske, Kieser, *Handbuch der Chemische, Technische Apparatur*, 1937, Berlin, 893 pp.

606. **Estimation of the Grinding Ability of Fine Grinding Apparatus from Observations of Solubility and Heat of Wetting.** BOLDEKER, K. *Verfahrenstechnik*, 1943 (3), 71–2. It is of importance to determine how far various processes go towards the limit of fine grinding. The finest possible grinding is quite remote from molecular dimensions, but with some materials, such as cellulose, sugar, molecular arrangement can be disordered to the extent (with cellulose) of the disappearance of the X-ray diagram. The energy thus absorbed and as determined by heat of solution or wetting of the ground material is correlated with the operation of the mill concerned, and its fine grinding capability determined. Results are presented for the grinding of sugar in carbon tetrachloride in ball mills and oscillating ball mills of various designs. The separated sugar product is then dissolved in water and the heat of the solution determined. The most efficient mill, both as to fineness and speed of grinding, as judged by heat of solution criteria, is the oscillating mill with steel balls.

607. **Attempt to Produce Carbon Black by Fine Grinding.** BREMNER, J. G. M. and COLPITT, J. H. *I.R.I. Trans.*, 1948, **24**, 35–51. Gas coal was ground to 2·5 microns, anthracite to 0·75 microns and pitch coke to 0·15 micron in periods from 1 to 5 days, using ¾-in. cast-iron balls. Low hydrogen content favoured fine grinding down to about 0·4% H. The authors succeeded in reducing re-coked pitch to 100 milli-mu, and in reducing rubber blacks in size, although spectral blacks of 75 milli-mu were increased in size on grinding. The products were also tested by incorporation in standard tyre tread mixes, the effects on hardness being proportional to fineness. (Imported U.S.A. channel blacks have a mean diameter of 30 milli-mu) 14 refs. (Interest in manufacturing carbon black by grinding has lapsed, even though the efficiency of conversion from natural gas is only 3%.)

608. **Dispersion of Pigments in Ball and Pebble Mills.** FISCHER, E. K. *Industr. Engng Chem. (Industr.)*, 1941, **33** (6), 1465–71. Optimum conditions for the operation of steel

ball mills for pigment dispersion have been investigated in mills from laboratory to production sizes. The author concluded that rate of grinding was proportional to the number of ball contacts and is greatest with very small balls, provided that viscosity of mix permitted cascading. The author showed that the rate of dispersion of iron blue in linseed oil of 2·2 to 3 poises is in order of the ball sizes, $\frac{1}{2}$, $\frac{3}{8}$, $\frac{1}{4}$, $\frac{3}{16}$ in. (greatest for $\frac{3}{16}$-in. balls) (R.A. Mott, *J. Soc. chem. Ind.*, Nov. 1950, found agreement except for $\frac{3}{16}$-in. balls).

609. **The Gases Locked up in Coal.** Fischer, F. *et al. BrennstChemie*, 1932, **13**, 209. *See under* Vacuum Ball Mill.

610. **Effect of Grinding on Kaolinite.** Gregg, S. J., Parker, T. W. and Stephens, M. J. *Clay Min. Bull.*, 1953, **2** (9), 34–44. During the disintegration of china clay by grinding, some chemical decomposition takes place.

611. **Milling Installations for Production of Dust.** Hermission, H. J. *Verfahrenstechnik*, 1938 (3), 75–80. Conventional installations are described, but the finest grinding is done by an oscillatory mill. (*See* Kiesskalt, *ibid.*, 1936, (1), 1.) Illustrations of all mills.

612. **Fine Grinding of Brittle Organic Products such as Roasted Coffee.** Kirschbaum, E. and Schmidt, H. *Chem.-Ing.-Tech.*, 1953, **25**, 598–600. *See* No. 2086.

613. **Pectin. Evidence of Molecular Constitution from Dry Grinding.** Lampitt, L. H. *et al. Chem. & Ind.* (*Rev.*), 4 Sept. 1954, p. 1113. There is evidence for molecular breakdown after 8000 hours' grinding in a ball mill. *See under* Foodstuffs.

614. **Effect of Grinding on Mica.** Mackenzie, R. C. and Milne, A. A. *Clay Min. Bull.*, 1953, **2** (9), 57–62. The effect of fine grinding on the lattice structure of micas is described.

615. **Fine Dusts in the Sub-microscopic Field, Shape Analysis and Course of Dry Grinding.** Meldau, R. *Verfahrenstechnik* 1940, (4), 103–6. Experimental results are reported for red beech, hickory and balsa woods, charcoal, lignite, coal and coke, mostly ground in oscillating mills. Photo-micrographs of samples obtained by electron optic enlargement (× 19 000) are presented for all materials. The lower limit of disintegration could not be determined, but appeared to be about 200–500 A. 10 refs.

616. **Superfine Grinding of Coke and other Materials.** Mott, R. A. *J. Soc. chem. Ind., Lond.*, 1950, **69**, 346–9. An account of an interesting series of experiments on the fine grinding of coal and coke on the laboratory scale. A review is given of some of the literature, particularly mentioning the paper by J. G. M. Bremner and J. H. Colpitts, with some of whose conclusions the author disagrees. It has been found possible to grind coke mechanically to a particle size of about 30 micro-mu, that is, as fine as the finest carbon blacks, but such an achievement is only of academic interest. Experimental details of the work which involved a ball mill, and both dry and wet grinding, are given, and it is concluded that dry grinding with $\frac{3}{16}$-in. balls can reduce the size of coal to 2 mu size in 1 hour and to 1·5 mu in 8 hours, after which grinding ceases owing to caking. Coke cakes less easily and grinding can proceed to 0·33 mu before caking occurs. Wet grinding, with coke, and using a relatively small proportion of coke, permits grinding down to 30 micro-mu. Distilled water containing 0·6 to 2·0% ammonia is the best medium found. Drying should be slow or else the ground material agglomerates to a hard mass. 7 refs.

617. **The Ball Milling of High Molecular Weight Materials.** Steurer, E. *Chem. Tech., Berlin*, 1943, **16** (1), 1–3. A review of published work on the reduction of high-molecular materials, with particular reference to cellulose. *See also under* Vibratory Ball Mill.

618. **Further Electron Microscope Studies on Colloidal Carbon and the Role of Surface in Rubber Reinforcement.** Wiegand, W. B. *India Rubb. World*, 1941, **105**, 270–2. *See under* Carbon, Graphite.

619. **The Preparation of Fines and Ultra Fines.** WINKLER, M. *Bergbautechnik*, 1953, 3, 63–70.

GRINDING AIDS: ADDITIVES

620. **Drying and Grinding of Metal Stearates.** O.T.S., U.S. Dept. Commerce, Washington, IR 13016, 1954, 3 pp. Obtainable from Lending Library Unit, D.S.I.R. The U.S.A. metallic stearates are usually dried by tunnel drying in a hot-air stream or by transfer drying. Some information is given on type of equipment and capacity. The behaviour of Al, Zn and Ca stearates in grinding processes is discussed and references are given to manufacturers of grinding equipment. Up to 1000 lb/h at −200-mesh and up to 700 lb/h at −325-mesh can be obtained by the 5-h.p. 2 DH Mikro-Pulverizer of the Pulverizing Machinery Co. for aluminium stearate.

621. **A Bibliography on Viscosity of and Workability Aids for Cement Paste.** ANON. *Rev. Matér. Constr. C.*, 1953 (459), 347–52; *Build. Sci. Abstr.*, July 1954, 963F.

622. **Evaluation of Surface Active Agents in Pigment Grinding.** ANON. *Paint, Oil, chem. Rev.*, 7 Nov. 1940, **102**, 70–6. The evaluation of some 50 agents is presented in tabular form. Some act as dispersing agents and others as settling agents. The effects of these agents on the mixing of various pigments are tabulated. Reference is made to the 1939 meeting at which the subject was first discussed. 14 refs, 1937–40.

623. **Disintegrating Solids.** BARTELL, F. E. (Assessor to Acheson Colloids Corporation). *Brit. Pat.*, 564418, 1941. The use of grinding aids, non-injurious, which can be sublimed after the process, particularly with graphite. With ammonium chloride and ammonium carbonate, graphite reaches 2–10 microns. Graphite can be used as a conductive addition to rubber and plastics. The grinding of other materials, e.g. talc, mica, vermiculite, and carbon black is assisted by these materials.

624. **Effects of Imbibition. Influence of Liquids on the Breaking Strength of Solids.** (In Italian.) BENEDICKS, C. *Chim. et. Industr.*, 1948, **30**, 103; *Rev. Métall.*, 1948, **45**, 9–18. The reduction in breaking strength on immersion was studied for: glass in water, ethanol and turpentine; chrome steel in aqueous caustic soda; zinc in mercury. A theoretical explanation is proposed. The effect is sometimes to increase the breaking stress.

625. **Further Ball Milling Studies on Pure Oxides.** BENNETT, D. G. and MCCREIGHT, L. R. *University of Illinois, Report*, No. 48, Oct. 1949, 12 pp. Experimental results indicate that the strength value of formed pure oxide bodies was increased by milling the fused raw material in a non-aqueous medium such as alcohol.

626. **Fine Dry Grinding.** BREYER, F. G. *U.S. Pat.*, 1985076, 1934. For dry grinding below 200 mesh, the energy required has been excessive for the reduction accomplished. It is suggested that a film of moisture or gases causes flocculation. Additives such as oleic acid, stearin, or hardwood pitch are suggested, and with less than 1% additive, reduction to 5 microns is attained for pumice. The claim for this treatment is applied to other materials such as zinc blende.

627. **The Effects of Chemical Agents in Comminution.** BROWN, J. H. *Massachusetts Institute of Technology, Progress Report N.Y.O.–7172, M.I.T.S.–28*, 31 July, 1955, 50–4. Results are as follows: (1) Considerably less grinding was accomplished when concentrations of NaOH, $CaCl_2$, Na_2SO_4 exceed 0·1 molar, in the grinding of gypsum. (2) Using various mixtures of methocel, methanol and glycerin in water and various strengths of methanol in glycerin, viscosity appeared to play a negligible part in the grinding of gypsum, except with glycerin and water, where the higher viscosity solutions gave inferior results. (3) Marked lowering of performance (product size) was seen when grinding with glycerin, benzene or methanol, as compared with water or 0·01 molar HCl. Addition of aerosol to lower surface tension gives improved results over all other agents tried. (4) Increase of water in solutions of glycerin methanol

and NaOH gives improved performance. The nature of the solute plays a significant part, however. This is yet to be investigated. Further experiments are reported in M.I.T.S.–29, 31 Oct. 1955, 56–9.

628. **Effect of the Medium on the Efficiency of Grinding in Ball Mills.** BYALKOVSKII, V. I., and KUDINOV, I. A. *Keram. Sbornik*, 1940 (10), 8–13; *Khim. Referat. Zhur.*, 1941, 4 (5), 114; *Ceramic Abstr.*, 1943, **22**, 121. The factors affecting grinding are described. The effect of surface active substances and adsorption effects are discussed. Tables are given showing how the sclerometric hardness varies with air grinding, wet grinding and contact with surface active agents. A full abstract is given.

629. **Wetting Agents in the Paint Industry.** CARR, W. *Off. Dig. Fed. Paint, Varn. Prod. Cl.*, 1951, **319**, 510–6. It is shown how ease of grinding, lower absorption, lower viscosity for a given concentration of pigment, can be obtained by use of wetting agents. The relation of molecular structure to wetting capacity is discussed.

630. **The Ratio of Water to Solids in Cylinder Grinding.** CREYKE, W. E. C. and WEBB, H. W. *Trans. Brit. Ceramic Soc.*, 1941, **40**, 55–72, Discussion, pp. 73–5. The variables influencing the efficiency of wet grinding in cylinder mills (ball and pebble mills) are: (1) speed and dimensions of cylinder, (2) size and dimensions of grinding media, (3) conditions of the charge. The salient features of all these variables are summarized before describing in detail the variable under consideration. Details of German and English grinding practice for a large number of materials are tabulated for the ratio of solids to water, experimental results are then tabulated, and finally the effect of viscosity and therefore of additives is discussed and the results of experimental work tabulated. The influence of the viscosity of the slip is stressed. A curve and tabulated data show a sharp diminution of efficiency, 1·35–1·25, by an increase in viscosity from 2 to 4 c.g.s. units; and how a predetermined amount of deflocculent, 0·16% sodium silicate, lowers the viscosity and promotes grinding efficiency. 35 refs. [P]

631. **The Effect of Mixing and Grinding Aids in Relation to Wetting and Dispersion.** DANIELL, F. K. *Off. Dig. Fed. Paint. Varn. Prod. Cl.*, 1952 (332), 633–8. *See under* Paint.

632. **Grinding Aids for Portland Cement.** DAWLEY, E. R. *Cement & Lime Manuf.*, 1944, **17**, 1–4; *Pit & Quarry*, July 1943, **36**, 57. (*See under* Cement, Dawley, Goddard.)

633. **Improvements in or Relating to Grinding and Pulverization.** DERBYSHIRE STONE, LTD., HOBDAY, J. W. Brit. Pat. 615587, 1946. An addition of up to 5% of wool grease to a wide range of minerals, e.g. limestone, gypsum, increases output and reduces power consumption, 0·5–1·0% of wool grease is an appropriate quantity.

634. **Abrasion Resistance and Surface Free Boundary Energy of Solid Substances.** ENGELHARDT, W. von. *Naturwissenschaften*, 15 Oct. 1946, **33**, 195–203. The paper deals with the effects on grinding of fluids in contact. *See under* Abrasion Grinding.

635. **Pigment Dispersion with Surface Active Agents.** FISCHER, E. K. and JEROME, C. W. *Industr. Engng Chem. (Industr.)*, 1943, **35**, 336–43. Some fourteen dispersing agents, chemical names and manufacturers given, were evaluated by their effects on degree of flocculation indicated by plastic viscosity and yield value, and on pigment strength development. The experiments were on a substantial scale, production roll mills being used. 29 refs.

636. **Grinding of Materials.** GODDARD, J. F., SUPER CEMENT, LTD. *Brit. Pat.* 350538, 1930. Material, e.g. cement clinker or gypsum, being ground in the dry state has mixed with it a segregating agent which when rubbed against the particles being ground generates static electricity and causes repulsion of the particles. A diffusing material can be used to assist the dispersion of the segregating agent, e.g. plaster of paris or hydraulic cement. The segregating agent is described as a resinous material.

This can be mixed first with the dispersing agent. (Stearine, potash and colophony have been proposed before this. Goddard considers them less satisfactory.)

637. **Effect of Dispersion on Cement Raw Materials.** KENNEDY, H. L. and MARDULIER, F. J. *Rock Prod.*, Aug. 1941, **44**, 76–7, 83. The undesirable loss of fines, and the undue loss of heat for sintering coarse particles can be mitigated by the use of a dispersing agent for attainment of a more uniform size of raw materials. An ounce or two of R.D.A. (not identified in the text) is sufficient for 600 lb of raw material.

638. **Addition of Ethyl Cellulose in Grinding of Pigments.** KAUTZ, H. *Farbe u. Lack*, 1939, 233–4; *Brit. chem. Abstr. B*, 1939, 746. Has marked wetting, dispersive and adsorptive properties and increases their hiding powers. With dry or damp pigment at 135° any water evaporates rapidly. With Prussian blue and carbon blacks, the use of a plasticizer facilitates dispersion in a varnish or solvent.

639. **The Process of Vibration Milling.** KIESSKALT, S. *Z. Ver. dtsch. Ing.*, 1949, **91** (13), 313–5. Investigations on milling machines, particularly on ball mills as used in the chemical industry, led to the development of the modern vibratory mill. A physico-chemical or mechanical chemical effect has been observed as a result of the operation wherein the rupture of molecular lattice structure can take place. It is suggested that the effect may be due to ultrasonic influence. Gaps in the knowledge of the vibratory mill have been closed during the last ten years by more thorough investigation and additions to the literature of the subject. A twelve-fold increase in surface area is obtained by grinding in polar fluids, e.g. isoamyl-alcohol, over that in water. Röntgen spectra of certain organic polymers disappear after an hour's grinding in a vibratory mill. For other materials, micron size is attainable. Applications to plastic fillers, powder metallurgy, etc., are cited. 29 refs.

640. **Accelerating the Wet Grinding of Refractory Materials.** KUKOLEV, G. V., MELNISHENKO, L. G. *Fireproof Mat., Moscow* (*Ogneupory*), 1948, **13**, 447–54. A study of the effects of various solutes upon the grinding of magnesite, dolomites, sands, etc., in experimental ball mills. The water content was 33%. Electrolytes had a selective effect, caustic soda accelerated magnesite but retarded dolomite. Soap accelerated dolomite but had no effect on magnesite. A number of curves showing the effect at different solute concentrations are given. These are explained on the basis of adsorption processes. Saturating the mill contents with carbon dioxide had a generally accelerating effect.

641. **Surface Energy of Solids.** KUZNETSOV, V. D. Gosudarstvennoe Isdatelstvo Tekhniko-Teoeticheskoi Literatury, Moscow, 1954, 213 pp. Chap. 6, Section 7. The effect of liquids and surface active agents on the failure of brittle solids. pp. 207–13. English translation from the Russian, 1957, H.M. Stationery Office, 8*s*. 6*d*. net.

642. **Grinding Dry Process Enamel. Effect of Small Quantities of Water.** MANSON, M. E. *J. Amer. ceramic Soc.*, 1938, **21**, 316–9. *See under* Enamel.

643. **Surface Activity.** MOILLIET, J. L. and COLLEY, B. 1951, E. & F. Spon, London. 366 pp. (Spon's Industrial Chemistry Series.) The physical chemistry, technical applications and chemical constitution of surface active agents.

644. **Superfine Grinding of Coke and Other Materials.** MOTT, R. A. *J. Soc. Chem. Ind. Lond.*, 1950, **69**, 346–9. Wet grinding, by avoiding caking, enables grinding to continue to a further stage. The effect of size and type of ball are discussed, and the benefits obtained by adding different alkalis and other materials during wet grinding are described and compared. [P]

645. **Free Boundary Surface Energy and Resistance to Grinding.** RAMMSAUER, R. *Kolloidzschr.*, 1951, **121**, 71–4. The surface effect of various solutions is considered. *See under* Abrasion Grinding.

646. **Aids to Clinker Grinding by Use of Dispersing Agent.** ROCKWOOD, N. C. *Rock*

Prod., May, 1939, **42**, 38. Discusses the beneficial effects of grinding aids, e.g. coal; which charges the balls and particles with electricity which keeps the particles apart. Discusses the effects and manner of application of T.V.A. (not identified in the text).

647. **Colloidal Carbon as a Grinding Aid in Portland Cement Manufacture.** SCHWEITZER, C. W. and CRAIG, A. E. *Industr. Engng Chem. (Industr.)*, 1940, **32**, 751–6. Experimental evidence supporting this effect: 0·32% on clinker increases the fineness of the cement by 30%, or decreases grinding time by 28%. Increased benefits with increased carbon dosage. Improved strength is shown. Up to 1% of carbon does not appreciably alter the properties of the cement except as to colour. Data are tabulated for effects on fineness and on strength properties of cement. 2 refs: (1) ASTM. Standards on Cement, 1928; (2) Columbian Carbon Co., *Columb. colloid. Carb.*, 1938, 141–5. *See also under* Cement, Wilsnack, G. C.

648. **Ball Milling and Mill Additions.** SPENCER-STRONG, G. H. *Ceramic Ind.*, 1946, **47** (2), 60. Efficiency in the milling of porcelain enamels depends on several factors, including the design of the mill, the speed of rotation, the grinding media, the mill charge, and the set of the enamel. These factors are discussed in some detail in this paper. The use of proper mill additions is of considerable importance in the milling operation, these additions, usually classified as suspending agents, refractories, electrolytes and opacifying or colouring agents, affecting not only the milling properties of the enamel but also its behaviour during application, drying and firing.

649. **The Effect of Surface Active Agents in Fine Grinding.** SZANTHO, E. von, *Z. Erzbergb. u. Metallhüttenw.*, 1949, **2**, 353–60. Experimental results of grinding quartzite and limestone with steel balls are presented in tabular and graphic form to show the effects of addition of reagents (flotigan and sodium oleate) to the wet pulp. Small additions, whose optima vary with the additive, result in increases in surface area of the ground product up to 100% above the increase without additive. Further additions result in a diminution of this increase, which is shown to be roughly parallel to the decrease in friction coefficient. This is much more marked in the case of sodium oleate addition, which, if large enough, almost completely inhibits the formation of new surface. Optima are in the neighbourhood of 300 g/ton for flotigan and 600 g/ton for sodium oleate. The effects of the additives are for small particles only ranging from 0·3 to 0·005 mm, being most marked for the smaller sizes. The additive is found to prevent overgrinding. Application is suggested for drilling operations. 9 refs., 1925–41.

650. **Process for Manufacture of Dispersoids.** TRAUN, H. O., Forschungs Lab. G.m.b.H., Hamburg. *Eng. Pat.*, 155836, 1919/22. Four types of Plauson mill are described. The method of addition of grinding aids is included in the specification.

651. **Grinding of Clinker.** WILSNACK, G. C., Edison Cement Corpn and Binney & Smith Corpn. *U.S. Pat.*, 2186792, 1937/40. 0·08–0·33% of colloidal carbon black effects reduction of power and time for grinding (and also the subsequent proportion of water when used).

HUMIDITY AND TEMPERATURE EFFECTS: EMBRITTLEMENT

652. **Grinding with Liquid Nitrogen.** ANON. *Chem. Engng*, 1951, **58** (6), 106–7. Impact pulverization of cold embrittled solids is announced by the Linde Air Products Co. Examples of the various materials which can be ground with advantage at temperatures as low as −320°F, and two photographs and two diagrams of the installation are given. *See also Food Engng*, 1951, **23**, 36–7, and *Rubb. Age, N.Y.*, 1950, **68**, 318.

653. **Low Temperature Grinding.** *Edg. & Allen News*, Jan. 1951. Description of low temperature grinding, which results in more regular-shaped particles.

654. **Low Temperature Grinding.—A New Process.** ANON. *Int. chem. Engng*, 1951, **32** (1), 13; *Chem. Engng*, 1951, **58** (6), 106–7. Cooling with liquid nitrogen as developed by Linde Air Products, Ltd., New York, is described. The advantages are reduction

of fire risk, safer for heat-sensitive and oxidizable materials or those with volatile constituents. Materials can be cooled to an optimum fragility.

655. **Non-Magnetic Taconite Treatment.** ANON. *Min. Congr. J., Wash.*, 1955, **41** (5), 40. Quenched ore for fine grinding. *See under* Iron Ore.

656. **Influence of Atmospheric Humidity on the Grinding and Screening of Solids.** (In German.) ALBINSSON, AKE. *Ark. Kemi*, 1953, 6 (4), 293–304. Dry grinding of felspar in full scale in an air-operated open-circuit ball mill gives about double the output and about double the quantity of fines when the moisture content of the material is 0·05% instead of 1%. Laboratory scale screening tests with ball mill dry-ground quartz, felspar and kaolin show a maximum screening output when the materials are in equilibrium with a r.h. of 40–60%. The output decreases rapidly for r.h. above 75% owing to capillary condensation. The observed decrease for very dry material is due to electrostatic charges. This decrease could be eliminated by ionization of the air (by Thorium B). Tests for determining the best particle size of felspar for rapid melting with sand, soda and lime are described. 8 figs., 6 refs.

657. **Freeze Grinding: A New Technique Using Liquid Nitrogen.** BRACKEN, A. and BRITTAINE, L. J. *Mfg. Chem.*, 1956, **27** (12), 497–9. The advantages of liquid nitrogen are pointed out, i.e. non-reactive, non-acid and very low boiling point, and the hardening effect on some materials as well as the weakening effect on others, e.g. iron, is indicated. The technique of use and the plant for freeze grinding are described. The granulation of polythene as against tearing at ordinary temperatures is illustrated. The freeze grinding of polythene and nylon is described and the scope of the process pointed out. 13 refs.

658. **The Grindability of Coal.** BROWN, R. L. *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1946, **10** (1), 10 pp. Includes a reference, page 10, to the sensitivity of coal to temperature and atmospheric conditions when being deformed.

659. **The Influence of Temperature on Grinding Efficiency.** DJINGHEUSIAN, L. E. *See* Nos. 55–7.

660. **How Solid Carbon Dioxide Assists in Grinding Low Melting Waxy or Plastic Solids.** DORRIS, T. B. *Chem. metall. Engng*, 1944, **51**, 114. Short description of the use of 'dry ice' for crushing.

661. **Grinding at Sub-normal and at Elevated Temperatures.** DRAPER, C. R. *Paint Manuf.*, 1944, **14** (2), 37–40. Cold for soap, resins, etc., warm for wetting of pigments with oils. Review in *Paint, Col. Oil Manuf.*, 1944, **17**, 254.

662. **The Influence of Temperature on the Dry Grinding Process.** ELLER, M. *Rev. Matér. Constr.*, 1928, 445; Translation in *Concrete*, 1929, **34** (4), 114; *Build. Sci. Abstr.*, 1929, **2**, 194. Tests on grinding clinker in a compound mill with insufficient ventilation. The degree of fineness was found to be inversely proportional to the temperature. With restored ventilation and normal output, the discharge temperature of the cement was 90–95°C.

663. **Low Temperature Grinding.** KANOWITZ. *Chem. metall. Engng*, May 1938, **45**. 236–7. Frequent cooling increases capacity and efficiency. Some figures are given. Reviewed in *Paint Col. Oil Manuf.*, 1938, **11**, 318.

664. **Energy/New Surface Relationship in the Crushing of Solids. VI. Effect of Temperature.** SCHULZ, N. F. *University of Minnesota Publication*, No. 3421, 1951; *Dissertation Abstracts*, 1952, 824. Experimental results showed that temperatures between 25° and 400°C had very little effect on the crushing of quartz, taconite, magnetite. *See* Djingheusian, No. 147.

665. **Improvements in or Relating to the Manufacture of Magnetic Cores from Magnetic Dust.** STANDARD TELEPHONES AND CABLES, WESTON, W. K., BUCKLEY, S. E. and JOHNSTON, T. *Brit. Pat.*, 587138, 1947. Brittle boundary phases are intentionally

introduced into tough nickel iron alloys to facilitate their disintegration into powder for the construction of dust cores for magnetic coils. Embrittlement by pouring into water is not satisfactory and is dangerous. The patent includes scattering the stream of molten magnetic material while pouring into water, by means of a water jet.

666. **The Influence of Temperature on the Grinding of Enamel.** VIELHABER, L. *Glas-Email-Keramo-Technik*, 1951, 2 (39), 2087. *See under* Enamel.

667. **Grinding Portland Cement.** WITTE, G. A., INTERNATIONAL PRECIPITATION CO. *U.S. Pat.*, 1803821, 1927/31. By grinding in an air of lower r.h. than that of the atmosphere attained by heating the air and/or the cement, the grinding time for a certain fineness is much reduced (and setting times are maintained).

LUBRICATION OF MACHINERY

668. **Rock Crushing and Screening Lubrication Features.** *Lubrication, N.Y.*, Oct. 1949; Reprinted in *Pit & Quarry*, Aug. and Sept. 1950, **43**. Part 1. Jaw crusher lubrication. Part 2. Lubrication of gyratory, vertical ring and hammer crushers. Part 3. Lubrication of screen equipment. All well illustrated.

669. **Forced Lubrication of Gyratory Crushers.** ANON. *Mine & Quarry Engng*, 1941, **6**, 310.

670. **Some Notes on Industrial Lubrication with Particular Reference to the Quarrying Industry.** COBBETT, R. F. *Cement, Lime & Grav.*, 1951, **25** (9), 337–47, 351. Good and proper lubricant is cheaper than breakdowns and wear.

671. **Grinding Mill with Micarta Bearings.** HORNE, F. *Engng & Min. J.*, 1937, **138** (10), 43. The bearings are laminated, with water lubrication. The power consumption by friction is less than for smaller metal bearings. About 50 gallons of water per minute are used, but oil is injected at shut down to lower starting torque and prevent rust. Such bearings are used in steel mills at 8000 lb/sq. in. A graphical comparison between the micarta and brass bearings is given. A rod mill with micarta bearings is illustrated.

672. **Comminution Plant.** LEBETER, F. *Mine & Quarry Engng*, 1950, **16**, 273, 327, 355, 391; 1951, **17**, 1471. A series of articles in which particular attention is paid to lubrication. The speed of crushers is discussed with regard to lubrication, from hammer mills at over 800 rev/min to impact crushers at 20 rev/min.

673. **Parallel Jaw Crusher with Lubricating Means within the Jaws.** MEINHARDT, M.E. *U.S. Pat.*, 2505132, 1950. An improvement in the technique of lubrication is described.

MILL VIBRATION

674. **Effects of Ball Mill Vibration.** ANON. *Ceramic Age*, April 1953, 62–3. The effects of normal vibration on the building structures and on other equipment, e.g. furnaces, is discussed. Methods of testing are suggested and the importance of the investigation of vibration effects is stressed.

675. **Effects of Ball Mill Vibration.** *Chem. Age, Lond.*, 14 Mar. 1953, **68** (1757), 417–9. Description of Dawe type 402 Vibration meter. Description of its use on the site in the neighbourhood of the Murex ball mills.

676. **Some Aspects of Machine Foundations.** R. HAMMONS. *Pwr & Wkrs Engng*, 1950, 45, 96. The transmission of vibration from one machine to another, or to adjoining structures, may be prevented by measures which are discussed.

NOISE CONTROL

677. **Practical Aspects of Noise Control in Crushed Stone Plants.** HOFTIJZER, A. B. *Pit & Quarry*, 1955, **47** (11), 76–8, 82. The author gives a brief description of noise

rating by decibels and the use of a sound level meter for rating it. Simple suggestions are given for lowering the noise on conveyors, vibrating screens and crushers.

AUTOMATIC CONTROL

678. **Controlled Feeder Increases Crushing 30%.** ANON. *Brick Clay Rec.*, Nov. 1952, **121** (5), 43. A 20–30% increased output of clay is achieved by means of a new automatic control of the feeding mechanism which is thereby made to work in step with the crusher through a Mosher control box.

679. **Metal Detection. Removal of Non-Magnetic Materials.** ANON. *Chem. Age, Lond.*, 15 Jan. 1955, 231. A midland firm manufactures an equipment (H.D.9). It is a heavy-duty equipment consisting of a search coil unit and a control cabinet (illustrated). Weighs 500 lb for a 36-in. conveyor. One coil lies under the conveyor and the coil at right angles encircles it. The cabinet sets up a high-frequency electromagnetic field in the coil unit which is adjusted to give a zero signal for no metal. When metal passes, the disturbance can be magnified to operate suitably any desired control device.

680. **Acoustic Mill Feed Controller.** ANON. *Elect. Rev., Lond.*, 11 May, 1951, **148**, 973. The content of the mill is determined from the noise level of the cascading coal and balls, the most significant noise frequency being about 4 kc/s. A microphone placed beneath the drum is connected to a main controller which, via amplifiers and relays, regulates the speed of the feed water around a set figure.

681. **Robot Ear Controls Tube Mill Feed.** *Engineer, Lond.*, 1951, **191**, 427–8; *Int. chem. Engng*, 1951, **33** (4), 158. An acoustic device suitable for the control of the feed in the continuous milling of chemicals and minerals is described. The noise level of the cascading grist and balls in contact with each other and with the liner of the mill determines the rate of feed of raw material to the mill. This prevents loss of efficiency by overloading, and excessive wear by running light.

682. **Feed Control on Grinding Mills.** *Facts f. Ind.*, 1956, **9** (3), Item 126. Cereal grinding mills equipped with the Heenatron control will adjust themselves to grists of varying hardness, requiring no manual resetting when the charge is changed from, say, maize to a hard grain like oats. The Heenatron is an electronically controlled d.c. motor which adjusts the rate of feed so as to keep the mill motor working at full load.

683. **Grinder Load Control Unit.** ANON. *Industrial Chemist*, Jan. 1956, **32** (372), 44. The Magco control unit made by a magnetic equipment company, is controlled by a current transformer mounted in one lead of the motor and consequently it responds accurately to variations of power taken by the main motor. A Magco vibratory feeder is recommended for use to facilitate control.

684. **A Sound Sensitive Grinding Mill Feed Control.** *Mining Equipment*, 1956, **7** (7), 29. The sound received by a microphone is changed to electric energy which is transmitted to a control unit operating a power relay which in turn operates the motor driving the mill feeder. The apparatus is very sensitive and is applicable to wet and dry grinding.

685. **Surface Production and Energy Requirements in the Crushing and Grinding of Solids.** ANSELM, W. *Zement-Kalk-Gips.*, 1953, **42** (1), 6. The overloading of impact crushers avoided by an electric control device. Idle time was reduced and output therefore increased.

686. **Roll Mill Control.** ATKINSON MILLING CO., MINNEAPOLIS. *Chem. Processing*, Jan. 1954, pp. 56–7. The discovery that slight adjustments of roll pressure cause change in the temperature of the issuing flour led the firm to develop a system for controlling the mill on the basis of thermometer readings. Besides controlling fineness, uniformity and facilitating inspection, power costs are reduced. A temperature difference of 3·5°F could increase the power consumption by 15%: with the constant

control provided, power consumption decreased by 10%. It is suggested that similar control could be applied to other grinding processes.

687. **Improvements in Controllers for Maintaining Proportionality or Substantial Proportionality between the Variations of a Pair of Variables.** BABCOCK AND WILCOX, LTD. *Brit. Pat.*, 717363, 1952. An electronic arrangement is shown for maintaining a constant relation or a desired relation between, say, the quantity of coal leaving a pulverizer and the quantity of gas passing through. The pressure differential is the measure of the quantities.

688. **Simple Magnet Alarm Protects Coal Pulverizers.** BEALS, R. A. *Industr. & Pwr*, 1954, **67**, 77. A magnetic collector on the coal chute separates tramp iron. A warning light indicates that the collector for the iron needs emptying.

689. **Relay System Cuts Pulverizing Costs.** GLOSS, E. A. *Elect. World, N.Y.* 25 Sept. 1950, **134**, 102–4. Equipment layout was revised, additional handling equipment and a system of electrical interlocking relays were installed. Output increased from 188 to 1000 lb/man-hour. Diagram of interlocking system.

690. **Automatic Control of Grinding Mills.** HARDINGE COMPANY INC. *Trans. Amer. Inst. min. (metall.) Engrs*, 1939, **134**; *Engng Min. J.*, Mar. 1939, 84. The Hardinge Company, York, Pa., has developed apparatus for the automatic control of grinding mills depending on the use of an 'electric ear' in the form of a microphone mounted close to the mill and connected to a power relay which reduces the rate of mill feed when the mill noise falls below a predetermined level, and increases the feed when the desired noise-level is exceeded. The apparatus is claimed to be sensitive but rugged, and applicable to dry and wet grinding mills in open and closed circuit with standard classifiers. Mills can be protected from overloading, prescribed fineness can be maintained, and optimum performance guaranteed within limits hitherto unattainable.

691. **New Electrical Devices in the Chemical Industry. The Electric Ear and the Electric Eye.** HOWAT, D. D. *Chem. Age, Lond.*, 1941, **44**, 303. Maximum sound will be produced inside a grinding mill when the balls or rods are striking freely against one another or against the liners, no cushion of any kind being interposed, and the entire energy being dissipated in the form of heat. If a complete cushion of finely-ground material exists around the balls, the sound will be at a minimum, no useful grinding being accomplished as the mill is overloaded. Between these two extremes there will be a stage at which just sufficient solid material occurs between the balls to ensure that large particles are fractured and broken but not overground. The sound produced under these conditions should indicate the optimum grinding efficiency. The increase in output obtained with this device is shown graphically.

692. **An Apparatus for Controlling and Recording the Circulating Load of a Mill.** KRITSKII, E. L. *Min. J. Spb. (Gornyi Zhurnal)*, 1955, 54; *Atomic Energy Research Establishment Library Translation*, 670, 1956, by R. D. Lowde. The apparatus comprises two units: (1) the measuring converter which is for the quantity of material loaded, as represented by the mean current and not the instantaneous current, into air pressure values (this is done by the Mekhanobr instrument); (2) a low-pressure ring meter used as the recording instrument. Diagrams.

693. **Electronic Control of Grinding.** LEA, P. *Facts f. Ind.*, 1955, **8** (10), Item 516. The rate of feed is varied automatically so as to maintain a constant maximum load on the motor. Increase of 50% in mill efficiency is claimed, and overloading of motor prevented. An electronically controlled vibratory feeder is also recommended. Cost of controller is £50. A complete set of equipment, with vibratory feeder and a permanent magnet separator for tramp metal, costs about £180.

694. **Automatic Control of Pulverizers.** MCSHANE, P. *Engng Min. J.*, 1948, **149** (9), 86–7. As the load on the pulverizer motor changes with variations in hardness, size, and quantity of feed, it can be used to alter the feed rate. Thus the load is kept constant

and maximum output results. Transformers in series with the motor regulate the feed rate by relays. Motors on the feeding device must have variable speeds. 3 figs.

695. **Industrial Control of Size Grading.** SHARRATT, E. *Trans. Brit. Ceram. Soc.*, 1949, 47 (1), 22–37.

696. **Automatic Control of the Grinding Circuit at the Marmora Concentrator.** STEFFENSON, P. L. and AUBREY, W. M. *Min. Engng, N.Y.*, 1957, **9** (1), 61–4. The ore contains 35–40% of magnetite. The mesh of grind is not determined as a satisfactory mesh of grind but by the physical requirements of the down-stream pelletizing operation. One large cyclone per unit is used, not multiple small ones. (In closed circuit.) A top size and an optimum amount of −325 mesh were arranged. The cyclone limited the top size. The amount of circulating load determines the proportion of −325 mesh in the cyclone overflow. The control originates in a weighing control instrument and in a vacuum instrument in the air line.

697. **Mill Feeding with Weight Control.** TAUBMANN, H. *Zement-Kalk-Gips.*, 1953, **6** (12), 445–9. A new direct acting, speed controlled, proportioning scale gives a constant weight flow. Variations in clinker hardness can be balanced automatically by this means. Diagrams; graphic presentation of operating data. 3 refs.

698. **Control System for an Impact Hammer Mill.** TULLIS, D. R. *Brit. Pat.*, 721675, 1951/55. An electronic device for governing the feeding mechanism and the defibring mechanism of a hammer mill is described.

ELECTRO-HYDRAULIC EFFECT

699. **Underwater Lightning Strikes Hard.** YUTKIN, L. *Soviet Weekly*, 18 July 1957. At a meeting at the Mining Institute, Moscow, the author described the application of underwater electric sparking and the resultant 'super high-pressure wave' to the cracking of boulders, drilling holes in carborundum and the high-speed crushing of rock. An electro-hydraulic hammer possesses an impact force of a third of a ton. Selective crushing is claimed.

MAGNETIC EFFECTS

700. **The Use of Coercivity in Grinding Tests.** DEVANEY, F. D. and COGHILL, W. H. *Trans. Amer. Inst. min. (metall.) Engrs*, 1939, **134**, 283–95; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 862; *Min. Tech.*, 1938, **2**. V. H. Gottschalk, in *Rep. Invest. U.S. Bur. Min.*, No. 3268, 1935, 83–90, established a linear relationship between magnetization, coercive force and the specific surface of comminuted particles. The value of this relationship in determining grinding efficiency has been shown by R. S. Dean, *Trans. Amer. Inst. min. (metall.) Engrs*, 1939, **134**, 324. Since the ordinary requirements for sub-sieve size and surface determinations involve long and tedious methods, the results of which are often questionable, by using magnetite as the material to be ground, a simple determination of coercive force by the coercimeter, requiring 10 minutes or less, can be transposed directly and accurately into units of relative surface. A curve is given (Dean, *ibid.*) showing a linear relation between work input and coercive force, using a drop-weight device; the Rittinger hypothesis is thus confirmed. Also the ratio, wet ball mill performance to drop weight performance, was found to be between 43 and 65%. 7 refs.

701. **Magnetite as a Standard Means for Measuring Grinding Efficiency.** DEAN, R. S. *Trans. Amer. Inst. min. (metall.) Engrs*, 1939, **134**, 324–6; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 660, 3 pp. The author assumes the validity of the Rittinger law, refers to the cumbersome methods for determining the new surface formed, although he assumes the validity of the hydrofluoric acid solution method, and proceeds to show that the crushing of magnetite furnishes a method for determining grinding efficiency quickly and accurately. The only requirement is a single determination of the relation between

the work input of the Gross-Zimmerley drop-weight machine and the coercive force of the resultant crushed magnetite. This relation is illustrated by a straight line-curve of linear scale. The coercive force is measured by the Davis method. It is described briefly.

702. **An Apparatus for Determining the Magnetic Constants of Mineral Powders,** GOTTSCHALK, V. H. and DAVIS, C. W. *Rep. Invest. U.S. Bur. Min.*, No. 3268, 1935, 51–65. An extended investigation has been made into coercive force and the magnetic constants of powders. Results of experiments show that the coercive force of magnetite is in direct proportion to the specific surface of the grains.

APPLICATION OF ULTRASONICS

703. **Disintegration and Dispersion by Ultrasonics.** *Sci. Libr. bibliogr. Ser.*, 1950, No. 699, 19 refs.

704. **Grinding by Ultrasonics.** *Chem. Tr. J.*, 19 June 1953, **132** (3446), 1480; *Engng Min. J.*, 1953, March, 109; June, 112. Reference is made to the Chayen process for maceration of bones in U.K., and the latest application of ultrasonics in U.S.A. is then described. J. Bassick has developed a pulverizer now in use in a plant at Reno, Nevada, in which four rotor blades spin at very high speed, up to 5000 rev/min. These never touch the rock, which is kept clear by a swiftly moving air cushion. The powder is fed at less than 2 in. diameter and the product is channelled into three hoppers: coarse, 200 mesh and 400 mesh. Output is up to 600 lb/h. Power consumption is normal, but wear of parts is much reduced. The materials milled were tactite and andalusite. Since milling tactite costs 1 dollar per ton in worn steel alone, the supersonic machine is regarded as more economic to use. A 60-h.p. V-8 engine was used to drive the rotor.

705. **Ultrasonics in Industry. 1. Methods of Generation.** ARNOLD, M. H. M. *Chem. & Process Engng*, 1953, **34** (11), 360–2. Ultrasonics suffers from over-popularization. Makers do not know what is required to be done and users do not know what apparatus is available. Hence the need for an appreciation of the subject. Seven methods of generation are described, and their limits, frequency and power characteristics are tabulated.

706. **A Select Bibliography of Published References to the Application of Ultrasonics.** CAMPBELL, N. Obtainable from Lending Library Unit, D.S.I.R. About 300 classified references, to 1949.

707. **Ultrasonic Pulverizer.** CLAUS, B. *Z. tech. Phys.*, 1935, **16** (7), 202–5. Describes the construction of a pulverizer which makes use of the property of piezo-quartz plates to produce oscillations, two parallel quartz plates being used and tuned to the same wavelength. The apparatus is dealt with under the oscillator, the transferer, the producer and the method of assembly. Finally, methods of use are considered, dealing with the two possibilities of direct and indirect pulverizing.

708. **The Possibility of Crushing Suspended Substances by Ultrasonics.** GARTNER, W. *Akust. Z. Beih.*, No. 1, 1953, 124–8. Experiments prove that the best crushing effect is obtained with frequencies of 500 kc/s applied to suspensions of 0·002 g/c.c. Graphs, illustrations, 12 refs.

709. **Ultrasonic Method for Testing the Homogeneity of Solids.** GIACOMINI, A. and BERTINI, A. *Ric. sci.*, 1939, **10**, 921; *Sci. Abstr. A*, 1940, 507. (1) Wave intensity. (2) Standing wave pattern.

710. **Some Applications of Ultrasonics to Industry.** KANEGIS, J. O.T.S., U.S. Dept. Commerce, Washington, IR 11585, 1953, p. 9. Obtainable from Lending Library Unit, D.S.I.R. While no technical application is known on the use of ultrasonics for *pulverizing* solid materials, it has been claimed to produce smaller grain size in metals during freezing.

711. **Absorption of Ultrasonic Waves in Water and Aqueous Suspensions.** KARTMANN, G. K. and FOCKE, A. B. *Phys. Rev.*, 1940, 57, 221; *Sci. Abstr. A*, 1940, 1238.

712. **The Dispersion of Clay Suspensions by Ultrasonic Waves: An Interpretation of Results Observed with the Electron Microscope.** MATHIEU-SICAUD, A. and LEVAVASSEUR, G. *C.R. Acad. Sci., Paris*, 1949, 228, 393. Suspensions of kaolinite and of montmorillonite, containing 0·5 g solid to 100 ml distilled water, were prepared, both as test suspensions and suspensions stabilized with NH_4OH. Each sample was treated with stationary waves of maximum strength, for successive 3-min periods, the temperature being kept constant and below 30°C. Measurements with a nephelometer showed that the degree of dispersion of the suspensions varies with the frequency and passes through a maximum at 960 kc/s for kaolinite and 320 kc/s for montmorillonite, whatever the suspension used initially. The electron microscope study demonstrated the superiority of ultrasonic waves over the usual chemical agents for obtaining sols of kaolinite comprising fine, monodispersed particles. The observations also indicated that each ultrasonic frequency corresponds to a different particular dimension which ranges from 1 to 1000 A. For the larger particles of montmorillonite, the dispersive frequency is lower and the action of the ultrasonic waves less definite. 4 figs.

713. **Attempt to Break up Clayey Rocks by Ultrasonics.** MILLOT, G. and NOISETTE, G. *C.R. Acad. Sci., Paris*, 1948, 227 (19), 974; *Amer. Ceramic Abstr.*, 1949, 32, 93.

714. **Dispersion of Soils by an Ultrasonic Method.** OLMSTEAD, L. B. *J. agric. Res.*, 1931, 42, 841–52. The mechanical dispersion of soil in water is produced by means of supersonic waves. The degree of dispersion is of the same order as that obtained in the rubbing method, but is more quickly reached. By neither method is the extraction of colloidal matter complete, small and decreasing amounts being obtained by successive treatments.

715. **Pigment Dispersion by Means of the Ultrasonorator.** PITTSBURG PAINT AND VARNISH PRODUCTION CLUB. *Amer. Paint J., Convention Daily*, 1949, 34 (6E), 20–4; *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1949 (298), 781–91. The factors affecting dispersion are discussed. Ease of dispersion for various pigments. Dispersion better with low viscosity of the medium and low pigment to medium ratio. (For criticism *see under* A. N. Thomson.)

716. **Grinding of Macro-molecules. Explanation of the Depolymerizing Effect of Ultrasonic Waves.** SCHMID, G. *Phys. Z.*, 1940, 41, 326–37. A theory of the depolymerization produced by ultrasonic waves is suggested. The breakdown is due to frictional forces which come into play in the interior of the solution. In the concn. range found in a gel, the liquid, in consequence of the variation in elastic properties and of the macro-mol, is not uniform, so that neighbouring particles in the solution do not execute equally strong vibrations. The free solvent vibrates through the meshes of a network of macro-mol, whilst the network itself cannot follow the ultrasonic vibrations on account of its inertia. This causes the development of frictional forces. It is shown that these forces would be sufficiently strong to break chemical linkings. It is also shown that in suitable solutions of high polymers, a dispersion of ultrasonic waves would be expected; such a phenomenon would provide a new method for investigation of the solutions.

717. **Ultrasonic Dispersion and Speed of Fracture.** SMEKAL, A. *Phys. Z.*, 1940, 41, 475; *Sci. Abstr. A*, 1941, 44, 291.

718. **Mineral Flotation with Ultrasonically Emulsified Collecting Reagents.** SUN, S. C., TU, L. Y. and AKERMAN, E. *A.I.M.M.E. Minerals Benef. Div. Annual Meeting, N.Y. City*, 1954. Any collector can be emulsified with aid of ultrasonic vibrations and emulsifiers. 18 pp., 12 refs.

719. **Ultrasonics as an Invasion into the Art of Pigment Dispersion.** THOMSON, A. N.

Off. Dig. Fed. Paint Varn. Prod. Cl., 1950, (308), 659–62. The conclusions of the Pittsburg Paint and Varnish Production Club are criticized. The immediate problem is to build a satisfactory continuous flow cell.

720. **Ultrasonic Preparation of Rock Samples.** WETZEL, W. *Erdöl. u. Kohle.*, 1950, 3, 212–4. The possibilities of this method are discussed, largely with reference to the preparation of paleontological and lithographic specimens, without grinding.

Crushing and Grinding Equipment

GENERAL PAPERS

721. **Steel Castings for Crushing Machinery.** British Steel Founders Association Brochure, 1952. Short account of mineral crushers.

722. **Economical Crushing and Grinding.** ANON. *Chem. Age, Lond.*, 1922, **6**, 228. A brief outline is given of various grinding and crushing machines, including jaw crushers, toothed revolving crushers, the Christy disintegrator, ball and tube mills, edge runners and magnetic separators.

723. **Crushing and Grinding Machinery.** ANON. *Chem. Engng*, 1922, **12**, 261–4. Hadfield crushing and grinding machines. Primary crushers are illustrated: 1923, **13**, 258–60. Vickers hammer mill and a gyratory crusher are described and illustrated.

724. **Portable Crushing Plant.** ANON. *Chem. Engng Min. Rev.*, 1950, **43**, 3–4. Crushing plant mounted on a 20 × 8-ft 8-ton semi-trailer drawn by a Commer 7-ton prime mover consists of a roll crusher, Marcy ball-mill, rotary spiral wire screen, amalgamating barrel for concentrating, amalgamating table with launders, Wilfley concentrating table, 400-gal water tank with centrifugal pump, 30-h.p. diesel engine, and a conveyor system.

725. **A Steel for Wearing Parts of Grinding Machinery and Similar Applications.** *Edg. Allen News*, 1953, **32** (368), 25–8. Chromax chromium alloy steel components for rod mills, crusher discs, liners, ball mill and tube mill parts are illustrated and described.

726. **British Mining Machinery.** *Edg. Allen News*, 1953, **32** (378), 265–8. Various pulverizers are described and illustrated—roll crusher, swing-claw crusher, multi-hammer mill.

727. **Pulverizing Materials. Test Plant for Grinding, Screening and Filtering.** *Engineering, Lond.*, 3 Aug. 1956, **182** (4717), 147–8. A description of the test house and equipment at the International Combustion Ltd., Derby, where commercial machines (smaller sizes) are available for test runs on samples under normal working conditions. Illustrated.

728. **Resurfacing Pulverizer Rollers.** ANON. *Engineering, Lond.*, 17 Aug. 1956, **182** (4719), 214–5. In maintenance of the surfaces of the rolls of coal pulverizing mills, until 1948 rebuilding was done by hand welding as many as five or six times before the rolls were scrapped. The disadvantage of hand welding is the time occupied and the development of cracks and the resulting splintering in use. A solution of these drawbacks has been produced by Metropolitan Vickers Electrical Co., Ltd., in the form of an automatic welder, where a preheat of the roll to 400°C does not affect the welder, and where the time of deposition is reduced by over 80%.

729. **Crushing, Grinding and Screening Equipment.** ANON. *Mach. Lloyd*, 1952, **23** (24A), 67–74. Accompanying translations in French and Spanish. Classifies size reduction equipment and describes the types. Emphasizes the 'golden rule' of size reduction practice—not to attempt a greater reduction than 5–1 in any one machine. Illustrated.

730. **Characteristics of Pulverized Coal. Effects of Type of Mill and Kind of Coal.** Proceedings of the Pulverized Fuel Conference, Harrogate, 1947. Institute of Fuel. Six types of mill were tested. Tube, ball, ring ball, emery, hammer and pig mill. The fineness and particle shape of product are discussed. *See under* Coal.

731. **Symposium on Production Problems.** *Rock Prod.*, March 1951, **54**, 92–8. A discussion covering a wide range of crushers and grinders, their characteristics in relation to output.

732. **Jaw Crushers, Cone Crushers, Ball and Pebble Mills, 1930–1935.** ANON. *Sci. Libr. bibliogr. Ser.* No. 226, 1936, (621.926). 198 refs.

733. **Drives for Ore Dressing Plant.** AREND, A. G. *Mine & Quarry Engng*, 1949, **15**, 219. The ratings of motors are discussed for jaw breakers, crusher rolls and ball mills.

734. **Improvements in or Relating to Pulverizing Mills.** BABCOCK AND WILCOX, LTD. *Brit. Pat.*, 668775, 1952. A pulverizing mill, with classifying means, to receive gas-borne particles and deliver the oversizes to a milling zone where fans direct the flow of two streams of gaseous fluid, one to a classifier with material delivered by the feeder and the other to carry from a milling zone material delivered there by the classifier.

735. **Technologie des Concasseurs, Broyeurs et Tamiseurs.** (Technology of Crushing and Grinding Machinery.) BLANC, M. E. C. 1924, Libraire Polytechnique Chez Bérangèr, Paris and Liège. 477 pp. The book deals entirely with machinery for size reduction and with some auxiliary equipment such as cyclones, sieves, and their dispositions. Theoretical aspects are not discussed. A chapter on stamp mills is included. Translation into German by H. Eckhardt, 1933, Springer, Berlin.

736. **Theoretical Study of the Crushing of Hard Materials. The Limits to Performance.** BLANC, M. E. C. *Rev. Industr. min.*, 1939, **435**, 106–12. An analysis of the mechanism of coarse crushing, illustrated by diagrammatic representations of the stresses in jaw, gyratory, roll and parallel plate crushers. The necessity of constant proportions in the dimensions of successive sections of the crusher is pointed out. The coupling of two crushers or grinders with different functions is condemned, although they may do useful work under particular circumstances. The importance of amortization and maintenance in relation to times of stoppage is pointed out. Therefore compound machines may not be advisable.

737. **Evolution in the Technique of Gravel Production.** BONJEAN, R. *Sci. et Industr. La Route*, 1938, 65; *Road Abstr.*, 1938–9, **5**, 338. A survey of the factors in the production of high-grade aggregate, with particular reference to operating conditions and the development of granulators.

738. **Big Portable Rock-Crushing Plant Produces over 200 tons per hour.** CONNOLLY, J. M. *Engng News Rec.*, 6 Nov. 1952, **149**, 136. 60% passing 1¼ in. and 40% passing ¼ in. mesh. A schematic diagram shows a jaw crusher. 54-in. roll crusher, washers, screens, etc., all on pneumatic tyres for easy transport and assembly into correct positions.

739. **Grinding and Crushing Machines.** CROSBIE, M. A. *J. Soc. chem. Ind. Lond.*, 1915, **34**, 320.

740. **Chert Stones for Pan Grinding Mills.** DAY-KIRKBY, W., SALT, R. S. and PROCTOR, G. P. *Crush. & Grind.*, 1932, **1**, 107.

741. **Handbook.** 1954, DENVER EQUIPMENT CO. A compact 800 pp. handbook giving diagrams and detailed tabulated data for equipment used in the mineral industry.

742. **Crushing and Grinding Equipment.** FARRANT, J. C. and NORTH, R. *Chemical Engineering Practice*, Vol. 3, Chap. 3, pp. 48–96. Butterworths Scientific Publications, 1957. The text is accompanied by many diagrams, performance tables and graphic presentations of performance of mechanical and fluid energy mills. A note on coal pulverization is appended. No. refs. [P]

743. **Multicut Mills.** FISHER SCIENTIFIC CO., NEW YORK. *Laboratory*, 1952, **21** (2), 55–6. Description of the Fischer Scientific Co. heavy duty 'Multicut Mill' for the

laboratory. Shearing plates are substituted for knives. Each plate face bears several interlocking sharp-edged teeth, which have extremely fine settings, from 0·001 in. to very coarse. Cuts soft materials.

744. **Crushing and Mixing under Controlled Conditions.** FRENKEL, Dr. M. S. *Engineering, Lond.*, 13 July 1956, **182** (4714), 41–2. The principle of the machine is a development of a continuous mixer, by the same author. (*Chem. Age, Lond.*, 25 June 1955. Enforced Order mixer, adjustable extruder, multi-mixer and dynamic gland.) It consists of two relatively rotating co-axial components with an annular space between them, and having operating surfaces of a complementary configuration, the material being forced along by the inner (screw) component. All reciprocating effects which are destructive to bearings are eliminated, and a large part of the crushing force is balanced within the system. The material is crushed against itself and the size range is large. The annular space has a diverging and converging course along the crusher. No performance, output or dimensional data are given. Diagrams.

745. **A Transportable Crushing and Grading Plant.** FRIDMAN, I. A. *Mech. arduous Wk., Moscow* (*Mekhan. Trudoemkikh. i tyazhelykh Rabot*), 1951, 5 (7), 23–6. Up to 40 cu. m of rock per hour can be crushed by operation of two or three workers.

746. **Treatment Plant Operation at Giant Yellowknife.** GROGAN, K. C. *Canad. Min. metall. Bull.*, April 1953, **46** (492), 211–2. (Gold-bearing ores.) Tabulated data are presented for jaw crushers, Simons cone crushers and ball mills, particularly with reference to wear of grinding surfaces. [P]

747. **Welded Crusher is Lighter, Cheaper, Stronger.** HERBRUCK, C. G. *Iron Age*, April, 1951, 102. The welded construction of a single roll crusher is described. A reduction of inertia is achieved as compared with casting and costs are reduced by up to 60%.

748. **Crushers Cinch Fuel Sizing, Cleaning.** HICKS, T. *Power*, 1951, **95** (7), 73–5; (8), 84–5. Various types of crushers and pulverizers are described; single and double roll crushers, hammer mills and Bradford breakers (combined breaker and mill). Selection of crushers and pulverizers for coal and power requirements are considered.

749. **Crushing and Grinding Appliances. The Connection between Type and Purpose.** HOLMAN, B. W. *Trans. Instn chem. Engrs, Lond.*, 1934, **12**, 186. Relation of crusher type to purpose. Comparisons between the rates of reduction obtained in practice with various rocks with different crushers. Machinery is classified into four categories.

750. **Beneficiation in 1950.** HOLT, G. J. *Min. Engng, N.Y.*, 1951, **190**, 122–5. Review of the mining industry in 1950 and mention of important developments in jaw crushers (66 × 84-in., 1000-ton/h), hydraulically supported gyratory crushers, and larger ball mills.

751. **Steam Generation.** INTERNATIONAL COMBUSTION, LTD. Catalogue; 25 Publications. (Bound.) Coal Milling, Publ. No. W.513; Lopulco Mill, Publ. No. G.493; Hardinge Conical Mill, Publ. No. G.525. Descriptions and illustrations are given and performance figures for some 36 industrial minerals are tabulated. Publications on screens, classifiers and all other equipment concerning pulverized fuel firing are included. [P]

752. **Control of Crushing Processes.** JACOBI, E. Berichte der Reichskohlen Kommissars H.3. 1940, Springer, Berlin, 41 pp., 72 figs. Abstract in *Feuerungstechnik*, 1941, **29**, 223. Crushers in general are considered in relation to greatest possible yield of the required size. An improved design for a two-roller crusher which approaches as near as possible the desired uniformity is presented.

753. **Economical Reduction and Sieving in Mineral Preparation with Modern Crushing and Grinding Machines and Vibrators.** KESPER, J. *Arch. Metallk.*, 1948, 2 (6), 187–92. A review of modern machines from jaw, roll and gyratory crushers to ball

mills, and methods of separation by sieving and by air and liquid separators. Methods of shortening the process of beneficiation are suggested.

754. **Symons Crusher in the Ceramic Industry and the Universal Grinding Plant.** KIRCHHOFF. *Ber. dtsch. keram. Ges.*, 1941, **22**, 135–49. *Ceramic Abstr.*, 1941, **20**, 222. The objection to the ball mill and the edge mill generally used for grinding, is that the product consists of rounded particles which are undesirable in ceramics. Describes the various types of Symons crushers and grinders. Illustrated.

755. **Pulverizers with Air Separation and Air Drying.** KOREN, W. A. *Industr. Engng Chem. (Industr.)*, 1938, **30**, 909–15. Deals with various types of air separators, shown in the diagrams as serving hammer mills located below the bases of the single or double cone separators.

756. **Development of Crushing and Grinding.** LEBETER, F. *Mine & Quarry Engng*, Dec. 1949, **15**, 385–93. Concludes a series of articles describing and illustrating equipment.

757. **Comminution Plant.** LEBETER, F. *Mine & Quarry Engng*, 1950, **16**, 273, 327, 355, 391; 1951, **17**, 1471. A series of articles on the factors influencing the choice of crushing and grinding equipment. The characteristics of individual mills are discussed and particular attention is paid to lubrication. 12 figs., 2 tables.

758. **Fundamentals of Mill Design.** MCNEILL, H. C. *Min. Engng, N.Y.*, 1953, **5** (9), 870–1. The practical factors in the designing of ore milling plants are described. (1) Selection of machinery. (2) Lowering labour costs. (3) Design considerations. (4) Electrical transmission. Ten points are specified for design of buildings.

759. **Crushing Machines and Sieves.** MAJER, J. *Berg u. Hüttenm. Mh.*, 1949, **94**, 85–6; 1950, **95**, 154. Crushing machines are classified and discussed. Vibrating sieves are stated to be the best for mechanical screening.

760. **How to Select the Crusher: Some of the Features upon which a Proper Choice Depends.** MICHAELSON, S. D. *Engng Min. J.*, 1940, (12), 41–5.

761. **Crushers for Stone and Ore.** MILLER, W. T. W. 1935, Van Nostrand, New York; 1935, Mining Publications, Ltd., London. Gives a historical survey and constructional details of a number of types of crusher, and considers particularly the effect of different types of crushing surface.

762. **The Evolution of Various Types of Crusher for Stone and Ore, and the Characteristics of Rocks as Affecting Abrasion in Crushing Machinery.** MILLER, W. T. W. and SARJANT, R. J. *Trans. ceram. Soc.*, 1936, **35** (11), 492–560; *Min. Proc. Instn civ. Engrs*, 1934–5, **239**, 39–95, 129–44; *Road Abstr.*, 1936, **3**, 622. Survey of the whole field of crusher development and operation, with special reference to grading of product and abrasion of crushing surfaces. Illustrated.

763. **Continuous Grinding.** MOLLER, C. A. *Trans. ceram. Soc.*, 1923, **22**, 12–9. Describes the various machines and arrangements for continuous grinding.

764. **New Trends in the Field of Crushing and Preparation of Hard Materials.** MOELLING, H. A. *Progressus*, 1953, **5** (E5), 22. A description of the large Esch gyratory crusher model KB VII/VIII and of the Esch impact breaker type EP.100 high-speed crusher (type not stated) and of the Esch Magneta Screen (3000 vibrations per min).

765. **Some Introductions in the Design of Reduction Plants and their Equipment.** NIMMO, A. *J. chem. Soc. S. Afr.*, Oct. 1940, **41**, 142–67. Includes flow sheets and numerous diagrams of equipment.

766. **Improved Feed Mechanism for Grinders or Pulverizers.** PORTIEUS, G. *Brit. Pat.* 581941, 1947. A hopper feed arrangement in which a reciprocating plunger feeds the material to the chamber.

767. **Dry Grinding Equipment.** ROBINSON, B. *Canad. Min. metall. Bull.*, Dec. 1954; Summary in *Min. Mag., N.Y.*, Feb. 1955, 119–20. The two main categories are: (1) fixed path mills—attrition (disc) mills, chaser mills, impact (hammer, cage) mills, roll mills, ring roll mills, ball race mills; (2) free path mills—jet mills (air blast), tumbling (ball, etc.) mills, cascade mills, vibrating mills.

768. **Coal Pulverizers and Grinding.** ROSIN, P. *Ber. Reichskohlenrates*, No. 25, 1930–31. Traces development of pulverizers and of pneumatic conveying and classifying technique. Compares grinding practice in cement works and in large power stations and discusses other aspects of coal pulverization. Deals also with air-swept mills, mill drying and the development of unit firing systems.

769. **Crushing and Grinding Machinery.** SEYMOUR, H. 1924, Ernest Benn, Ltd., Chemical Engineering Library. 144 pp. Description with illustrations of crushing and grinding machinery, but not fine grinding machinery.

770. **Preliminary and Secondary Breaking Machinery.** SEYMOUR, H. *Crush. & Grind.*, 1931, **1** (2), 35.

771. **Primary Crushing. Progress Reports 1, 2 and 3 and Summary of Field Tests.** SHEPPARD, M. and WITHEROW, C. M. *Rep. Invest. U.S. Bur. Min.*, Nos. 3377, 3380, 3390, 3432, 1938/9. *See under* Crushing and Grinding Practice, General Papers.

772. **Crushing Action of Stoker Feed Screws.** SHOTTS, R. Q. Alabama State Mines Experimental Station. Contribution No. 1. Sept. 1947.

773. **Protection of Crushing Machinery against Foreign Substances.** SIEBERT, R. *Chem. Fabr.*, 1939, **12**, 157; *Ceramic Abstr.*, 1942, **21**, 65. To prevent damage from foreign substances such as pieces of iron, in ores or slags, rolls are protected by springs attached to a sliding frame, Symons crushers have a top frame which can be lifted against strong springs, and hammer mills have special grooves to catch steel pieces. The best protection is afforded by the removal of tramp iron by magnetic means. Several types of magnets are described.

774. **A Textbook of Ore Dressing.** TRUSCOTT, S. J. 1923, Macmillan & Co., Ltd., London. 668 pp. Chap. III, 36–173. Chap. IV, 174–94. Comminution. Machinery and Practice. Early pan mills, ringroller mills, stamp mills, ball and tube mills, beater mills pin mills, crusher rolls, jaw and gyratory crushers are well illustrated.

775. **Crushing and Grinding, Part I.** URE, S. G. *Chem. & Ind.* (*Rev.*), 21 Nov. 1924, **43**, 1144–52. Description of the various kinds of primary crushers and grinders, jaw crushers, horizontal and vertical disc crushers, gyratory crushers. Illustrations of each. Shows that Rittinger law holds for large particles, but in finer sizes the surface produced is greater than the power input. Concludes that the true law probably lies between those of Kick and Rittinger.

776. **Crushing and Grinding, Part II.** URE, S. G. *Chem. & Ind.* (*Rev.*), 1925, **44**, 321–6, 349–53, 383. (1) Rotary breakers and crushing rolls. (2) Hammer crushers and disintegrators. (3) Pin mills, squirrel cage mills and K.E.K. centrifugal mill. Numerous illustrations.

777. **Crushing and Grinding, Part III. Ball and Tube Mills.** URE, S. G. *Chem. & Ind.* (*Rev.*), 1925, **44** (22), 551–9. Descriptions with illustrations of ring roller and vertical ball mills, the Bradley Giant Griffin mill, the Bradley three-roll mill, the Sturtevant mill, the Huntingdon and Raymond roller mills and the Fuller Pulverizing mill (ball ring mill).

778. **Choosing Ore Feeders for Beneficiation Plant.** WALVOORD, W. *Min. Engng, N.Y.*, 1955, **7** (2), 131–4. In addition to descriptive matter, a chart is presented showing the characteristics, tabulated, of 16 varieties of feeder.

779. **How to Protect Crusher Motors Against Operating Hazards.** WRIGHT, H. A.

and BELLINGER, T. F. *Engng Min. J.*, 1955, **156** (7), 88–91. Causes of damage are discussed and methods of avoiding damage are recommended. Normally, adequate protection is not obtained from standard commercial motor controllers.

WEAR OF EQUIPMENT

780. **Wear of Ball Media.** *See under* Fine Reductions (Ball Wear).

781. **How Clay Machinery Metals Wear During Plant Operations.** ANON. *Brick Clay Rec.*, 1938, **92** (4), 24. With a view to reducing maintenance costs, tests were carried out on various materials at the Engineering Experiment Station, Ohio State University, and it was found that certain alloy cast irons are best for mill knives, muller tyres and die liners, and malleable irons for dry pan screen plates. The tests are described, the effects of chrome finishing and heat treatment being mentioned, and the results are given in four tables: (1) Chemical composition and wear loss data of pug-mill knife materials; (2) Composition and wear loss data of muller tyre materials; (3) Wearing behaviour of dry pan screen plates; and (4) Composition, heat treatment, and wear loss data of dry pan runner plates.

782. **Manganese Crusher Parts Rebuilt.** *Iron Age*, 7 Feb. 1952, 194. Crusher cones rebuilt with manganese steel and hard surfaced by electric arc deposit of austenitic steel, are stated to outlast original castings.

783. **Repair of Worn Crusher Parts.** ANON. *Nickel Steel Topics*, 1946, **15**, 10; *Nickel Bull.*, 1946, **19**, 153. A cast steel swing jaw of an ore-crusher in service in the Noranda Mines, Quebec, which had become worn in contact with a manganese steel wear-plate, has been successfully rebuilt by facing to size and shape by a welded overlay of nickel steel. Earlier repair effected by the same method had proved highly successful, giving a continuous service life of six years. The electrodes used contained carbon 0·17% (max) with 4·5–5·25% of nickel. The good machining qualities of the deposit, and the fact that it work-hardens to about 380 Brinell, render the nickel steel eminently suitable for this type of service.

784. **Coal Pulverizing.** *Nickel Topics*, 1951, 4 (3), 8. Results of test comparisons between Ni-Hard and White Iron Hammers show an 80% longer life of the former. [P]

785. **Mining and Dressing of Low Grade Ores.** *O.E.E.C. Technical Assistance Mission*, No. 127, 1953. *O.E.E.C., Paris*. Obtainable from H.M. Stationery Office. Appendix III. At the Salzgitter-Callrecht iron ore dressing plant, the following data were provided: The wear on the jaw crusher plates was 0·59–0·76 g/ton; on the cone crusher plates and liners 5 g/ton; and on balls in the ball mill 792 g/ton throughput of ore.

786. **Hot Hardness of Hard Facing Alloys.** AVERY, H. S. *Weld. J., Easton P.A.*, 1950, **29**, 552–79. States that the most appropriate hard facing materials for crusher parts are martensitic irons, martensitic steels and austenitic steels for positions of light, medium and heavy impact respectively. Detailed description of these, and tables of data. (These tables are reproduced by R. V. Riley in *Chem. and Process Engng*, 1953, **34** (1), 11, in his review of the literature of size reduction. Hammer mills are regarded as medium impact applications. In jaw crushers where impact stresses are high, hard alloys usually fracture before they wear out. Manganese nickel weld deposits (electric arc methods) usually give a suitable repair.

787. **Mathematics of Crushing and Grinding.** BOND, F. C. Symposium on Mineral Dressing, 1952, Paper No. 2. Institution of Mining and Metallurgy. The author states that metal wear cost including parts thrown away as worn parts often approaches the power cost. The amount of wear can be expressed as lb/ton ground, but is more conveniently expressed as kWh/lb of metal wear. Wear is not predictable from laboratory tests. It varies widely according to abrasiveness of material and conditions of grinding. Estimates are as follows:

	kWh/lb metal
Wet Grinding	
Balls and rods	7
Mill lining	30
Dry Grinding	
Balls and rods	35
Mill lining	150
Hammer mills	5–10
Fine crushing	30
Coarse crushing	40

788. **Grinding with a Hammer Mill at Norris Dam.** CADENA, F. *Trans. Amer. Inst. Min. (metall.) Engrs*, 1938, **129**, 185–94; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 824, 1937. Production and maintenance of hammer mills for sand production at Norris Dam, T.V.A. The paper deals with three specific sets of data on the wear of the mill components and the costs of tool steel and manganese steel grate bars. [P]

789. **Wear Tests.** CLIMAX MOLYBDENUM Co., New York City. *Min. Engng, N.Y.*, 1950, **187** (6), 738. Reprint gratis, 32 pp.

790. **Wearing Properties of Some Metals in Clay Plant Operation. Part I. Pug Mill Knives, Muller Tires, Runner Plates, Screen Plates.** DIERKER, A. H. and EVERHART, J. O. *Bull. Ohio Engng Exp. Sta.*, No. 97, 1937.

791. **Wear-Resisting Metals.** GIBSON, W. A. *Rock Prod.*, 1940, **43**, 28; *Ceramic Abstr.*, 1940, **19**, 261. He discusses the use of impact and wear-resisting welding rods and castings for the various wearing parts of pulverizers and grinders.

792. **Treatment Plant Operation at Giant Yellowknife.** GROGAN, K. C. *Canad. Min. metall. Bull.*, Apr. 1953, **46** (492), 211–2. (Gold-bearing ores.) Tabulated data for jaw crushers, Simons cone crushers and ball mills are presented, particularly with regard to wear of grinding surfaces. [P]

793. **Specially Hard Alloy Cast Iron for Resistance to Abrasion.** HALLETT, M. M. and EVEREST, A. B. *Proc. Inst. Brit. Foundrym.*, 1938–9, **32**, 115; *Ceramic Abstr.*, 1941, **20**, 99.

794. **The Hollinger Crushing Plant.** HOLLINGER MILL STAFF. *Canad. Min. metall. Bull.*, Sept. 1953, **46** (497), 551–76. Among performance data, etc., the data on wear are tabulated for the jaw and cone crushers and fine crushing rolls. [P]

795. **Operational Experience with Coal Pulverizing Equipment.** HUBNER, M. *Mitteilungen der Vereinigung der Grosskesselbesitzer*, 1953 (22), 320–6. These hammer mills have a capacity of 5 tonne/hour for a feed of 0–25 mm size and 12% moisture, the latter being dried by hot air in the mill. Information is given on (1) wear on hammers and housing, and the relation between feed hardness, service life and costs, and (2) fineness of grinding and power costs. [P]

796. **Increasing the Useful Life of Pulverizer Components.** KIBRICK, P. S. and KONTOROV, B. M. *Za Ekonomiyu Topliva*, 1949, (5), 23–4.

797. **A Contribution on the Subject of Wear in Coal Grinding Equipment.** KNOCH, F. *Feuerungstechnik*, 1942, **30**, 135–9. The paper deals with the wear of the relevant parts of the Anger pneumatic impact mill, the hammer mill (moving hammers) and the K.S.G. Naszkohlenmuhle (rigid hammer plates). The action of the wearing parts is illustrated diagrammatically.

798. **Causes of Wear in Percussion Mills (for Brown Coal) and Possibilities for its Prevention or Diminution.** KOPPE, P. *Wärme*, 1941, **64**, 155–8. The nature and causes of wear in percussion mills, especially of the striker heads, are discussed and modifications and devices designed to resist rapid wear described. Reduction in wear is usually accompanied by unsatisfactory output, but designs are presented for which it is claimed that the wear is reduced without detriment to the output.

799. **Steels for the Refractory and Heavy Clay Industries.** MILES, G. W. and KEITH, W. B. *Edg. Allen News*, 1954, **33** (380), 29. A tabular summary is given of the wear on fixed and moving jaws of jaw crushers for 9 types of steel. [P]

800. **Problems of Wear in the Ore Dressing Installations of the Mitterberger Copper Mine.** PRANTER, H. *Berg u. hüttenm. Mh.*, 1955, **100** (1), 66–9. Results of wear measurements in wet ball milling are tabulated, together with the wear observations in the pre-treatment Symons crushers and prall mills. Comparisons are made between amount of wear and increasing product output.

801. **Automatic Hard Facing of Worn Pulverizer Parts Pays Off.** RUGGIE, R. *Pwr Engng*, April 1954, **58**, 72–3; *Fuel Abstr.*, Sept. 1954, 2466. To attain the minimum maintenance on pulverizer parts subjected to severe abrasion in grinding coal to 70% passing a 200-mesh sieve, the Cleveland Electric Illuminating Co. employ hard surfacing of mill rings and rolls. The problems overcome are described.

802. **Wear on Jaw Crusher Plates.** TAGGART, A. F. *Handbook of Mineral Dressing*, 1945, Wiley & Sons, New York, and Chapman & Hall, London; 4·06 and 4·07. General aspects and costs.

803. **Grinding Tests on a Fuller Peters Mill.** WINTER, H. and FLAMM, A. *Brennst.-Wärmekr.*, 1953, **5**, 45–9, 76–9. Tests on ball and ball race wear are discussed. Although the grindability of various cokes tested differed considerably, the specific wear (grammes/tonne) remained almost constant. By using special alloys, the specific wear for the two races and the balls together was reduced to 25 grammes/tonne. Graphical and tabular representation of results, and two illustrations. [P]

PLASTIC BEARINGS

804. **Bearings Made from Pressed Plastics for Use in Preparation Machines.** KISSLER, R. *TonindustrZtg*, 1941, **65**, 510. Data are tabulated on the use of pressed plastics in the bearings of cement mills, stone crushers, roller crushers concerned with mining, roller crushers 750 mm diameter × 500 mm, and centrifugal mills 1750 mm crate diameter. Precautions to be taken when using plastics for this purpose are enumerated; if these are observed the life of the bearings will attain to or even exceed, that of metal bearings.

Coarse Reduction

SKULL BREAKER

805. **Skull Breaker in a Limestone Quarry.** MOSSIER, McH. *Inform. Circ. U.S. Bur. Min.*, No. 472, 1948, 4 pp. A skull breaker, comprising a Mn-steel ball (of 2 tons) suspended from a crane (suspension illustrated) has completely displaced secondary blasting in a limestone quarry at Pleasant Gap, Centre County, Pennsylvania. The steel ball is roughly spherical; the suspension chain has a life of the order of 10 days. The skull breaker increases safety of the workmen and the number of operating days, and lowers the mining costs. It might be applied advantageously to other mines.

CRUSHER ROLLS

806. **Arc Welding of Crusher Rolls.** ANON. *Brick Clay Rec.*, 1940, **96**, 27; *Amer. Ceramic Abstr.*, 1941, **20**, 267. Worn crusher rolls may be repaired economically by welding metal on to the concave portion in the centre of the rolls.

807. **Reduced Wear by Suspending Grinding Units.** ANON. *Brick Clay Rec.*, 1949, **115** (4), 4, 62. A description is given of a new roll grinding system installed in a brickworks. A feature is the use of suspended rotating rolls which damp vibration, so reducing wear and tear. Three sets of roll-type crushers are hung by steel cables; no heavy foundations are required and the supporting members are light steel columns. The large screening mechanism is described. 5 figs.

808. **Facts About Crushing Rolls.** ANON. *Brit. Clayw.*, 1922, **31** (360), 7.

809. **Care of Crushing Rolls.** ANON. *Brit. Clayw.*, 1931, **40**, 314. Vibration in crushing rolls can be recognized by varying thicknesses of the clay, whereas if the rolls are working properly the cakes are of uniform thickness. The symmetrical nature of the changes in thickness enables the vibrations to be distinguished from irregularity caused by a stone between the rolls. Grooved rolls are a common cause of poor crushing.

810. **The Wear and Tear of Crushing Rolls.** ANON. *Brit. Clayw.*, 1943, **52**, 38, 71. The wear on rolls due to vibration is described and suggestions are made for reducing it. Excessive wear is caused by clay falling over the ends of the rolls and reaching the bearings. This should be prevented by vertical metal plates (known as 'hopper cheeks') which are fitted near to the end of the rolls. The adjustment of crushing rolls is discussed. The methods of trimming and dressing the rolls are described in detail.

811. **Crushing Rolls.** ANON. *Edg. Allen News*, 1948, **27** (313), 83–5. In outlining some features of certain crushing rolls which are secondary crushers, their minimum production of fines is considered to be an advantage. High-speed rolls usually have smooth faces and work at peripheral speeds of 700–1000 ft/min. 5 figs.

812. **Some Secondary Crushing Machines.** *Edg. Allen News*, 1952, **31** (364), 245–6; (365), 270–1. Illustrated description of high-speed crushing rolls for sizes ½ in. and less. Table of mechanical details. Brief details are given of cubing and kibbling rolls and some short general notes applicable to both high- and medium-speed rolls.

813. **The Crusher in the New Skinningrove Plant.** ANON. *Edg. Allen News*, 1954, **33** (381), 55–6. Brief description of crusher roll, double roll type, toothed, 5 ft diameter, 4 ft 6 in. wide, 160 rev/min passes lumps up to 36 × 18 × 18 in. and 300 ton/h at 7 × 4 in. product.

814. **Chalk Crushing and Screening Plant.** ANON. *Engineering, Lond.*, 16 Jan. 1953, **175** (4538), 94. A description of the 30 × 50-in. long Fraser and Chalmers toothed single

roll crusher for chalk at the Chinnor Cement & Lime Co., Ltd., Oxfordshire. Lumps up to 3 ft can be fed. The breaker plate can be adjusted up to 9 in. discharge.

815. **Grinding Plants for the Cement Industry.** *Escher Wyss News*, 1950/51, **23–4**, 101–3. Mainly concerned with ball mill plants with classification. Drawing of completely welded ball mill, which results in better stress distribution than riveted designs and facilitates fitment of manholes, etc.

816. **Slugger Roll Crusher.** ANON. *Min. Mag., Lond.*, 1955, **42** (4), 234. A Chesterfield firm announces the largest single slugger roll crusher to crush shale overburden in Malaya. It will crush shale 4 × 4 × 1½ ft to less than 10 in.

817. **Stone Crushers.** ANON. *Mine & Quarry Engng*, 1942, **7** (7), 269. Single-pair high-speed rolls, without gear, and having each roll separately driven is now quite usual practice. The cost of the two-motor equipment will probably prove comparable with that of the countershaft equipment, and is likely to prove more free from trouble. It can be employed for breaking down oversize pieces of stone. A convenient and satisfactory reduction ratio of large size of feed to large size of product is 2½ to 3 to 1 if the roll surface is rough. Single-roll, gear-driven machines are also in use as sledge or breaking-down machines; a fair number appear to be in use in the U.S.A., but there is little call for them here.

818. **Rock Crusher.** *Rock Prod.*, 1953, **56** (9), 68. A two-corrugated roll crusher is described and illustrated. The Waldrip Engineering Company's machine has two 30-in. diameter fluted rolls, one concave and the other convex. The compression is by hydraulic means, oil and gas, which allows release of tramp iron, etc.

819. **Unit Operations.** BROWN, G. G. and ASSOCIATES. 1950, Wiley & Sons, New York, 1950, Chapman & Hall, London. Size reduction of solids, pp. 25–49, includes a mathematical analysis of the forces at the crusher rolls.

820. **Velocity of Hit in Rock Crushing.** FAHRENWALD, A. W., NEWTON, J. and HERKENHOFF, E. *Engng Min. J.*, 1937, **138** (12), 45–8. Much work was carried out on the above problem with a roll crusher, but was abandoned as an unsatisfactory approach in favour of drop weight tests. Results of crushing tests with the rolls are tabulated, and the construction of the roll crusher is described (11 in. diameter, 1 in. face). [P]

821. **Welded Crusher is Lighter, Cheaper, Stronger.** HERBRUCK, C. G. *Iron Age*, April, 1951, 102. The welded construction of a single roll crusher is described. A reduction of inertia is achieved as compared with casting, and costs are reduced by up to 60%.

822. **Roller Crushers.** MILLER, W. T. W. and BADGER, G. *Proc. Instn mech. Engrs, Lond.*, 1939, **141** (1), 69–80; Discussion, 563–9; *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1939, **3**, 619. A study of the characteristics of roller crushers for the reduction of ore, stone, coal, etc. Single roll crushers have been developed for semi-hard slippery materials such as phosphate, gypsum, shale, etc. Two roll crushers are the most numerous. Three roll crushers are not always successful. Two examples are described and their defects explained. Four roll machines have been useful for coal. Six roll crushers are not very common. Reasons are given for their restricted application. Taylor's 3-stage coal breaker and the 2-roll and disc Simplex machine are described. The factors which influence the performance of rolls are examined in detail and a formula for obtaining their capacity is given. The correlation of angle of nip and feed size, and their effect on the diameter of smooth rolls is emphasized. A time factor diagram is given to show the reason why rolls of large diameter can be run with higher circumferential speeds. Figures of normal power consumption are specified. 10 diagrams, 20 photographs of toothed and plain roll machines. 40 refs.

823. **Some Considerations on Rolls.** RAUPACH, R., MASCHINENFABRIK. *TonindustrZtg*, 1940, **64**, 569–70. Reasons for poor performance of crushing rolls are discussed.

824. **Secondary Crushing Machinery.** SEYMOUR, H. *Crush. & Grind.*, 1931, **1**, 35–6. Description with diagrams of Jeffrey single roll crusher, and of a swing hammer pulverizer.

825. **Primary Crushing, Progress Report No. 1.** SHEPPARD, M. and WITHEROW, C. M. *Rep. Invest. U.S. Bur. Min.*, No. 3377, 1938, 11 pp. An investigation into the output of primary crushers in relation to their design and operation. *Gyratory* and *roll* crushers were investigated. Results on the crushing of limestone are embodied in 14 graphs, 6 tables and a long summary. [P]

826. **Practical Merits and Theoretical Values in the Preparation of Clay.** SPINGLER, K. *TonindustrZtg*, 1942, **66**, 403. A discussion is given of the apparatus used in the crushing of clay. The output for fine rolls calculated in cu. m/h ranges from 1·5 for 10 h.p. to 8·0 for 50 h.p. The output for crushing rolls per hour ranges from 1000 at 5 h.p. to 4000 at 12 h.p. A standardization and simplification of the apparatus is suggested. [P]

827. **Grinding Rolls as a Preparation Machine.** SPINGLER, K. *Ziegelindustrie*, 1950, **3**, 509; 1951, **4**, 1217. Some practical hints are given on the use of crushing rolls in the brick industry. 3 figs.

828. **Trouble Free Operation of Roll Crushers.** TOLSCHIN, A. I. and PANIN, S. A. *Fireproof Mat., Moscow (Ogneupory)*, 1952, **17**, 333. A brief note on the smooth operation of roll crushers, which are distinguished by the absence of gear and pinion between the rolls and the presence of flywheels on each roll.

829. **Roller Crushers.** VAGANOV, N. P. *Fireproof Mat., Moscow (Ogneupory)*, 1934, **2**, 44. An expression is derived connecting 13 operation variables, power requirements and crusher dimensions.

830. **Reconstruction of Bearings in Crushing Rolls.** ZAKHAROV, I. F. *Fireproof Mat., Moscow (Ogneupory)*, 1952, **17**, 42–3.

HAMMER AND BEATER MILLS (COARSE REDUCTION)

831. **Grinding of Minerals in Germany 1939–1945.** *B.I.O.S. Report*, No. 1356, H.M. Stationery Office. The swing hammer mill becomes specially important for the disintegration of fibrous and tough material, e.g. for clay, bones, leather, wood, asbestos.

832. **The Power Requirements of Impact Mills.** ANON. *Arch. Wärmew.*, 1941, **22** (11), 240. Expressions are given for the power requirements of prall mills, and the performance and power requirements are presented in curve and block diagrams. [P]

833. **Hammer Mill and Vibratory Feeders Increase Plant Efficiency.** ANON. *Brick Clay Rec.*, 1939, **94** (5), 14. The hammer mill produces granular particles at 6-mesh fineness, which are better for manufacture than the flat, flaky particles given by smooth rolls. A mill with 66 hammers, driven by a 150-h.p. motor through a 14-strand V-belt drive, handles 500 tons of clay per day. Vibratory feeders give a more uniform feed than disc feeders, and do not clog. Each can be controlled by the pugmill man.

834. **The British Jeffrey Diamond Rock Buster.** *Chem. Age, Lond.*, 26 Mar. 1955, 745. It can reduce any hard friable material from a maximum feed of 36 in. down to 90% passing a 1½-in. sieve in one stage. Easy adjustment makes possible a wide variation of size of product. Available in two sizes. Performance for limestone, carbide and sintered clay is quoted. The rotor weighs 2 tons (or 5 tons for larger model). A cubic-shaped product is claimed. Breakage is by the rotor hammer bar impact, impact against bars in the upper part of the housing, rebound against oncoming material, and finally crushing between the rotor bars and adjustable rings.

835. **The Prall Mill.** ANON. *Colliery Engng*, 1952, **29** (10), 433–4. The mill consists of three parts; a centrifugal impeller rotating clockwise at 1000 rev/min; a moving

baffle plate rotating anticlockwise at 1500 rev/min and a stationary baffle plate. The material is fed through the stationary plate and forced by the impeller into repeated contact between the two baffle plates until small enough to leave through the adjustable gap between the plates. The driving shafts are concentric from one side. The chamber is in the shallow double cone, with the feed opposite the impeller.

836. **Swing Claw Crusher.** *Edg. Allen News*, June 1953, **32** (372), 123–4. The illustration shows claw hammers mounted on a shaft. The machine is stated to reduce coal from 1$\frac{1}{2}$ in. to $\frac{1}{4}$ in. The material passes through a sieve at the bottom. Diagrams and tables of dimensions. The machine is suitable for coal and other brittle materials. Sizes range from 20×12 in. to 40×48 in. *See ibid.*, 1955, **34** (395), 101–2.

837. **Pulverizing in One Machine.** *Edg. Allen News*, April 1954, **33** (382), 8. For crushing, e.g. limestone or slag, from 2 to 3 in. down to products from $\frac{3}{8}$ to $\frac{1}{8}$ in. and under, the Stag K.B. rotary pulverizer is suitable. The swing hammers are mounted on eccentric pins for adjustment to allow for wear. Hinged breaker plate and slide-in screens are embodied. Capacities are up to 20 ton/h. Data for various materials are tabulated. [P]

838. **Making Cubical Chippings.** *Edg. Allen News*, April 1955, **34** (394), 80–1. The Stag K.B. rotary granulator is described and illustrated, and performance figures (for several rocks) of the four sizes are tabulated. A cubical product for road stone is claimed, by virtue of the design of liners and adjustable breaker plate. The heavy steel rotor is provided with three adjustable swing hammers. [P]

839. **The Use of Resilient Impact Mills in the Ceramic Industry.** ANON. *Euro-Ceramic*, 1955, **5**, 95. With the Berger mill (Germany), the material being fed collides first with flying pieces in the impact chamber before coming in contact with the rotor blades. It is claimed that the material breaks along natural cracks and cleavage planes by this means, and lower power consumption is attained.

840. **A Robust Coal Pulverizer.** ANON. *Gas. J.*, 27 Sept. 1950, **263**, 606. A brief description of a new swing hammer pulverizer built in capacities from 10 to 250 ton/h producing 80–90% through $\frac{1}{8}$-in. mesh in one operation. A simple external adjustment for product size during running is provided.

841. **The Advantage of Impeller Breaker in the Field of Ceramic Products.** ANON. *International Ceramics*, 1953, (2), 14. Primary and secondary crushing are effected and produce a cubic grain down to the finest fractions. The feed is flung by rotating blades on to impact plates which give way for tramp iron, etc., which is expelled. The impeller works without screens, has a low power consumption, is vibrationless and needs only light foundations. Maintenance is simple and operation costs low. The crushing effect is said to be much greater than in ordinary jaw breakers, Symons crushers, or edge runners.

842. **Swing Hammer Pulverizers.** Equipment in the Vanderbijl Coke Oven Plant in South Africa. *Iron Coal Tr. Rev.*, 1947, **155**, 1048.

843. **Hammer Mills.** *Mach. Lloyd*, 1951, **23** (24A), 67. Principles of size reduction. Distinction between crushing, grinding and pulverizing is made. Hammer mills are treated in detail. The general principle of size reduction is restated, i.e. it is inadvisable to attempt a greater reduction than 5:1.

844. **Stone Crushers.** ANON. *Mine & Quarry Engng*, 1942, **7** (11), 269. The hammer mill is a high-speed machine and its mechanical efficiency is probably higher than that of any other crusher. 'Smalls' and 'fines' are characteristics of the products of hammer mills. There are quite a number of differences in design; most machines are fitted with a single shaft and a single set of hammers which drive the stone against a hard and heavy breaker plate, where most of the reduction is effected. Some have two shafts and two sets of hammers and the feed is delivered and held in a form of heavy

bar cage above and between the arc of action of the hammers. Others are fitted with swing hammers and some with fixed.

845. **The New Hammer Mill 'Imperator'.** ANON. *TonindustrZtg*, 1923, **42** (4), 2. The mill consists of a cylindrical casing in which is a revolving shaft with hammers attached. The casing is fitted at the bottom with a grating which can be regulated according to the size of material required. The mill is capable of dealing with material from egg to cocoa-nut size. The hammers are not of the rigid type, so that, on meeting with hard, foreign matter, e.g. pieces of iron, they are turned aside.

846. **Impact Breaking.** ANON. *TonindustrZtg*, 1953, **77** (7/8), 144–6. A discussion of the mechanism of impact breaking. Expressions are deduced relating the speed and weight of the particles, free path of the particles and other factors. It is concluded that for certain materials, the method has advantages, but for others it is not economic.

847. **German Industry Fair, Hanover.** *TonindustrZtg*, 1953, **77** (11/12), 212. Six illustrations of current prallmuhlen types of impact mills. The rock is projected by rotors against the walls or bars or curved segments from which it rebounds to the incoming feed before being moved round for further similar treatment. A large proportion of the reduction is thus done by impact between the lumps themselves. In *TonindustrZtg*, May 1953, 9/10, 181, a list of the German firms making prall mills is given.

848. **Coal Crushing Equipment. Installation and Application.** ANDERSON, J. W. L. *Iron Coal Tr. Rev.*, 1938, **136**, 405–7. A description of breakers and systems for crushing coal. Illustrations of hammer crushers. (Knives or hammers fitted to heads revolving against breaker plates.)

849. **Beater Mills. Variable Length Beater Arms.** BABCOCK AND WILCOX, LTD. *Brit. Pat.* 688523, 1952. The particle size of the product can be changed by varying the peripheral speed of the beater arms and/or the effective diameter of the beater circle. In the drawing, the change in effective diameter was attained by arranging for the several pairs of beater arms to slide in and out of the shaft, and thus vary in effective length. Another method was the use of a suitable driving motor to vary the speed of the mill. Air removal of the fines is arranged.

850. **Report of Tests Carried out on the Swing Hammer Pulverizer.** BIRD, C. E. *J. chem. Soc. S. Afr.*, 1951, **52** (11), 109–17. The amount of fines decreases with reduced motor speed and with increase in bar openings. The speed can be adjusted for coarse or fine product without unduly affecting the capacity of the machine. For the particular machine used, speeds of 800 rev/min and 1160 rev/min are suggested for the two products. [P]

851. **Impact Crushers for both Primary and Secondary Crushing.** BRADFORD HILLS QUARRY INC. (LENHART, W. B.). *Rock Prod.*, 1954, **57** (2), 81–2.

852. **Rock Crusher Having Controlled Rock Screening and Co-operating Grate Means.** FOGLE, F. D. *U.S. Pat.* 2661158, 1951/53. A hammer mill with pivoted hammers mounted on two reversible spindles throws the broken stone against beams of graded sizes and apertures disposed along the side wall of the mill and above the hammers, so that broken material not passing between the beams is returned to the hammers. There is a grating below each shaft.

853. **Size Reduction by Impact.** FOWLER, J. T. *Chem. metall. Engng*, 1938, **45**, 230–3. Rules governing efficiency and cost are outlined. Describes the action of swing hammer mills for various purposes, and illustrates the giant swing hammer mill 54 × 48 in. in a cement mill for reducing limestone from run of mine size to 1½ in. in one operation. Operating principles are itemized.

854. **The Sintering of Northamptonshire Iron Ore. A Production Plant Study of Factors Affecting Sinter Quality.** GILLINGS, D. W. *et al. J. Iron St. Inst.*, 1951, **167**, 400–

39. The special problems associated with the crushing of Northamptonshire iron stone. It was found that the build-up of fines on the stationary breaker plate of a swing hammer mill could stop crushing when the hammer tips became worn. This build-up could be most satisfactorily avoided by a new design incorporating two hammer rolls mounted side by side without a stationary breaker plate. The mill was somewhat similar to a high-speed double roll crusher, but with the advantage that the hammers keep clean owing to the high speed of operation. Cf. Young, C. W. *Brit. Pat.* 578236, 1946.

855. **Control and Segregation in Dry Grinding.** Hendryx, D. B. *Brick Clay Rec.*, Jan. 1954, 46. A detailed comparison between the merits of hammer and pan mills for grinding in the heavy clay industry. *See under* Ceramics.

856. **Screen Changer for Hammer Mills.** Keiper, E. H. *U.S. Pat.* 2710149, 1955. The object is to provide a number of screens for the hammer mill, housed within the mill and capable of being positioned by remote control, say, from the floor above the mill without a person having to go down to change and lock the screen.

857. **The Possibilities of the Prallmuhle in the Stone and Mineral Industries. Pt. I.** Lehmann, H., Buchartowski, H. G. and Parpart, J. *TonindustrZtg*, 1951, 75, 372–77. Although impact mills have served well for coarse and medium reduction, their satisfactory application to fine pulverizing is not yet fully accepted although they have had wide use. The paper is devoted to results obtained for various hard rocks and to comparisons with the results of other pulverizers, e.g. hammer, Simons and ball mill, with graphic presentations. 8 refs. [P]

858. **The Possibilities of the Impact Mill (Prallmuhle) in the Stone and Mineral Industry. Pt. 2.** Lehmann, H., Meffert, H. and Buchartowski, H. G. (Clausthal). *TonindustrZtg*, 1952, 76, 9–14. A tabular representation of the twelve types of prall mill technical data. Graphical representation of results in pulverizing furnace slag and other by-products, phonolith, limestone, burnt lime, cement clinker, burnt clay, grog, etc. The mill is suitable also for preparing aggregates. [P]

859. **Crushing, Conveying and Screening.** McBride, W. J. *Edg. Allen News*, 1948, 27, 123. The author deals with secondary crushing and the hammer mill in particular. It is of primary importance to study all details in order to determine the type and size of machine required for a particular job. In general, there are six types of secondary crusher, although the jaw, cone, and gyratory crushers when used as secondary crushers are similar in behaviour as when used as primary crushers. The hammer mill is the best all-round secondary crusher, as the resultant product can be varied by several means; little space is required; worn parts are easily replaceable; a cubical product is obtained; and machines may be had in widely varying sizes. Examples of mill performance are tabulated. Power consumption compares favourably with that of other types of crushers; replacement costs will vary with conditions, but some guide is given. 2 tables.

860. **Some Observations on the Use of Hammer Mills in the Ceramic Industry.** Massieye, J. (Société Française Céramique). *L'Industrie céramique*, 1953 (7/8), 155–8. The results of laboratory experiments on the grinding of clay are presented graphically and lead to the following conclusions. With this type of mill it is difficult to vary the granulation of the clay, and changing the grating has a negligible influence, and only wastes time. This may not matter with clay, but for hard materials it is important. The hammer mills in current use do not permit any large variation in the granulation, even for ingredients for refractories, although it is larger than for soft materials. The experimental results obtained, confirm once more previous findings on an industrial scale. It is concluded that it is very difficult, if not impossible, to obtain a given granulation with a given material by means of a hammer mill.

861. **Investigations on the Possibilities of Modern Machines. Impact Hammer Mills.** Meinecke, E. *Z. Erzbergb. Metallhüttenw.*, Aug. 1952, 5, 314–19. In the comminution

of Siegerland Siderite, the advantages of hammer mills over jaw breakers are enumerated in four aspects, and hammer mills are considered eminently superior to all other forms of primary crushers.

862. **Development in Impact Crushing in the U.S.A.** MITTAG, C. *Z. Ver. dtsch. Ing.*, 1952, **94** (13), 365–7. Whereas prall mills have only been used in Germany since the end of the second world war (*see under* Puffe), they have been used in U.S.A. for 30 years. The construction of single and double roll prall mills is shown, also a transportable double roll breaker is illustrated; and tables are given of performance under varying conditions and under varying energy consumption. The use is increasing in the U.S.A. It has had extremely wide use in road building. [P]

863. **The Prall Pulverizer in Technical Processes.** MITTAG, C. *Chem.-Ing.-Tech.*, 1953, **25** (4), 179–80. A review of the development of impact pulverization and a description of the breaker and its application. A table of data of product sizes in relation to mill speed is included. [P]

864. **Hammer Mill with Decentric Rotors.** POLLITZ, H. C., IOWA MANUFACTURING Co. *U.S. Pat.* 2563958, 1951; *Off. Gaz. U.S. Pat. Off.*, 1951, **649** (2), 416. The grate is arranged eccentrically to the shaft, the gap narrowing in the direction of rotation.

865. **Machine for Breaking Stone, etc., by Means of Impact.** POYSER, R. G: and MARSDEN, LTD., H. R. *U.S. Pat.* 2705596, 1955. A pair of four hammer shafts revolve towards each other. The stone falls vertically in two streams and is struck by the hammers and projected to the casing or breaker bars. Less wear of parts is claimed.

866. **How the Impact Crusher Can Cut Costs.** PUFFE, E. *Engng Min. J.*, 1955, **156** (7), 98–100. Most so-called hammer mills are impact breakers. They are replacing jaw crushers, roll mills, gyratory crushers and even ball mills, wherever they can apply. Tabulated data show that output per hour for the Mechernich lead-bearing sandstone is much greater and the h.p./cu. m of product is much less than those of the other mills. [P]

867. **Combined Hammer Mill Crushing and Oversize Separating Apparatus.** PULVERIZING MACHINERY Co. *U.S. Pat.* 2552596, 1951; *Off. Gaz. U.S. Pat. Off.*, 1951, **646** (3), 776.

868. **Schlagmühle (Hammer Mills).** SEILER, LTD., H. (ZURICH). *Swiss Pat.* 296418, 1951/54. An arrangement of two sieves to a hammer mill, whereby two desired sizes of product can be obtained simultaneously.

869. **Secondary Crushing Machinery.** SEYMOUR, H. *Crush. & Grind.*, 1931, **1**, 35. Several examples of crushing rolls and swing hammer pulverizers are illustrated and described.

870. **Pulverizing and Grinding Machine.** SIMON CARVES, LTD. *Brit. Pat.* 598040, 1949. Solid passed first to a swinging hammer type mill, then through an axial eye or opening into a beater mill.

871. **Impact Crushing.** SPIES, H. *Colliery Guard.*, 1954, **189**, 382–3. The Hazemag Impeller breaker is described and illustrated. The mill has an inlet and outlet screen, two sets of impact plates and a single rotor. Results are shown graphically of the breakage of rock and coal in respect of granularity and size of product against quantity of input, up to 45 tons per hour. [P]

872. **Automatic Control of Conveyor Belt Feeding to Hammer Mills.** WAEBER, H. G. *Zement-Kalk-Gips*, 1953, **6** (1), 23–4. Overcharging of hammer mills is a frequent cause of trouble in operation. Brown Boveri has produced a device for stopping the charging when there is danger of overloading and resuming when normal. Idle time of the crusher is thus reduced.

873. **How to Increase the Performance of Hammer Mills.** WAEBER, H. G. *Zement-*

Kalk-Gips, 1953, **6** (3), 78–80. The author describes a Brown Boveri & Co. device which permits the flywheel energy of the crusher to act in unison with the output impulses of the driving motor and so increase the crushing energy. The characteristic curves of the three-phase slip-ring motor are altered by the device. Overloading is avoided and idle time is thereby reduced.

874. **Reversible Swing Hammer Crusher with Adjustable Breaker Plates.** WRIGHT, F. J. (Assessor to Jeffrey Manufacturing Co.). *U.S. Pat.* 2478733, 1949; *Paint, Varn. Prod. Mgr*, 1949, **29** (10), 21.

JAW CRUSHERS

875. **Jaw Crushers.** *See also under* Aggregate.

876. **Two New Crusher Jaw Developments.** ANON. *Claycraft*, 1945, **18**, 384. Crusher jaws can be designed to overcome various difficulties, but not all of them, so that the machine should be chosen in accordance with the results required. A new design with a flattened centre portion and an enlarged zone towards the outlet end reduces wear on the plates and improves the shape of the product, thus making it unnecessary to use jaws with 'staggered' teeth or one worn and one unworn plate. Excessive wear at the toe, which occurs from various causes, can be overcome by the use of the new segmental jaw plates, the new sections being dropped in successively at the top. This reduces maintenance costs, since each segment gives longer wear.

877. **Crushing Hard Materials.** *Edg. Allen News*, 1953, **30**, 99–101, 125–7, 148–9, 173–4. Description with illustrations of jaw crushers, with tabulated machine data. Appropriate screens are described.

878. **Jaw Granulators.** *Edg. Allen News*, 1953, **32** (367), 8–9. Illustrations of jaw granulators, with table of mechanical details and power requirements for various sizes.

879. **Kue-Ken Balanced-Jaw Crusher.** ANON. *Engineering, Lond.*, 15 Feb. 1952, **173** (4490), 203. Sole rights to manufacture in U.K. the American Straub range of Kue-Ken jaw crushers are acquired by Armstrong-Whitworth. Direct pressure and no rubbing or abrasion. Wear is diminished, but the crusher has special features for taking up wear. Rate of 350–425 strokes per min. Various sizes 4–200 ton/h, 7½ to 50 h.p.

880. **Giant Crushers.** ANON. *Metallurgia, Manchr*, 1953, **48** (286), 92. The International Nickel Corporation has installed five jaw crushers underground. Each is capable of crushing 450 ton/h. Each swing jaw weighs 16¾ tons.

881. **Underground Crushing Station.** ANON. *Mine & Quarry Engng*, April 1955, 168–9. At the Kurunavaara iron ore mine in Sweden, open-pit mining is being changed to underground mining, with an increase from 6–7 million to 12 million tons per annum. The boulder crushers, jaw crushers, are illustrated. These are the Morgardshammar Boulder crushers weighing 120 tons, with a 71 × 55-in. opening.

882. **Stone Crushers.** ANON. *Mine & Quarry Engng*, Nov. 1942, **7**, 268. Jaw crushers are usually arranged with a swing jaw, which obtains its motion through a toggle from the pitman and the pitman, in turn, from the shaft. A variant of this design is the granulating crusher in which the jaw-stock is fitted to the shaft direct; this results in the jaw-stock having a form of rolling movement greater than that of the pitman type, but it only serves to good purpose where the material and operating conditions are suitable. In the normal sizes the jaw crusher may be considered a general-purpose machine, as it can be used for general reduction of various types of material. Its most suitable application is for the reduction of oversize lumps within its capacity, and the mean reduction ratio of the feed-product should be kept down to, say, 3 or 3½ to 1.

883. **Study of Crusher Types.** ANON. *Pierres et Min.*, 1934, **6** (61–2), 959–70. Jaw-type machines: Blake type and single-toggle machines are considered. The single-toggle type has heavy wear on the jaws and, on account of the large production of fines, requires more power. Jaw wear may amount to 0·9 to 1 kg per 1000 kg of product, but is more often about 0·6 kg for hard rock, and falls as low as 0·01 kg for soft limestone (manganese steel jaw-plates). For hard rock the gyratory machine is more economical. The main advantages of jaw crushers are simplicity and strength, ease of adjustment, and more cubical stone due to the economic possibility of using toothed jaws. To maintain a cubical product the jaw-plates must be replaced before the teeth have disappeared: such replacement would be too expensive with gyratory crushers. A Blake type of crusher is described in which the jaw faces are parallel for a short distance from the discharge opening and the whole of the material is sized by the parallel zone. Jaw wear does not average more than 0·3 kg per 1000 kg for hard rock or 0·45 kg in exceptional cases. Power consumption is 33% less than for a normal machine. Gyratory crushers.—The various designs are discussed. The gyratory crusher gives a more cubical product than either crushing rolls or disc crushers. Jaw wear is at least six times less than with single-toggle jaw crushers, though the cost of effecting replacements, when required, is about double. Rather shorter sections deal with rolls, disc crushers, cone crushers, impact crushers and other types, and provide various operating data. (Joisel, 1950, considers that the presence of teeth does not materially improve the size or shape of the product.)

884. **A New Design in Crushers.** ANON. *Quarry Mgrs' J.*, 1947, **30**, 576. This single jaw crusher incorporates the principle of crushing without rubbing, the rock being nipped and crushed squarely with minimum slipping and very small wear of jaw-plates. A sealed oil-bath lubrication system is fitted, and the crusher operates at 350–400 crushing strokes per min., which is a considerable increase in speed over the older types of machine.

885. **The Mining and Dressing of Low Grade Ores in Europe.** AHLMANN, B. (Royal Institute Technology, Stockholm.) *O.E.E.C. Technical Assistance Mission*, No. 127, 1953. *O.E.E.C., Paris*, 1955. Obtainable from H.M. Stationery Office. Some investigations of jaw crushers, pp. 271–2. The main object of the work was to determine whether useful predictions can be made with regard to capacity, wear, etc., from standard laboratory tests using standard laboratory jaw crushers. Preliminary tests on 50 different samples of ores and rocks showed that such factors as texture of the ore and internal flaws make reliable analysis of the results too difficult. It was decided therefore to use nine selected materials of known strength, and as free as possible from flaws and impurities. In testing these materials under all crusher variables, the wear and the variables of the product were recorded. It was found that capacity was *not* directly proportional to throw as implied in Gieseking's formula. Cf. Shergold, 1954, who found that no reasonable proportion of sizes below ½ in. could be obtained from seven types of rock whatever the setting of the jaw granulator. [P]

886. **The Preparation of Ceramic Raw Materials. VII.** AVENHAUS, W. *Ziegelindustrie*, 1950, **3**, 388; 1951, **4**, 941. Jaw crushers and edge-runners are discussed. Mechanical calculations are given and a table indicates the size, power consumption, weight, output and crushing ratio of seven crusher sizes for crushing limestones. 3 figs, 1 table.

887. **Means for Reducing Bulging of Crusher Jaw Face Plates.** BAKER, R. V. *U.S. Pat.* 2609154, 1949/52. A diamond pattern on the crushing face of jaw crushers is claimed to reduce bulging and distortion.

888. **Some Results of Research Work on Jaw Crushers.** BAUMANN, V. A. *Mech. Constr., Moscow* (*Mekhan. Stroit.*), 1954, **11** (7), 21–8. A translation may be consulted at D.S.I.R., Ref. Records Section, 22988. An account is given of the research carried out on single-toggle jaw crushers for the study of the fragmentation of stone in the crusher, the optimum angle of grab for crushing highly resistant stones, the minimum

extent of movement of the moving jaw, the maximum load on the crushing plate, the distribution of load and the optimum kinematics of the crusher. It was found possible to study these factors by measuring the nature and amount of stresses affecting a fixed crushing plate as a function of the movement of the swing jaw. Various sizes of crusher were used, up to 600 × 900 mm. Hydraulic capsules were fitted to the fixed jaw, the electrical system is described, resulting oscillograms presented, the geometric characteristics relevant to the research illustrated and results tabulated. It was found that when crushing hardstone in modern swing jaw crushers, frequent breakages occurred, productivity was low and too much fines produced. The experimental work which has extended over a number of years, has enabled these defects to be overcome. The crushing effort as found in the present experiments did not agree with computed effort. A formula is suggested, however, which may be of practical value for designing complex swinging jaw stone crushers. The Levenson formula for efficiency is more closely defined. The causes of variation in efficiency are analysed and a maximum angle of grab of 20° is recommended. 15 figs, 5 tables. *See ibid.*, 1950, 7 (9).

889. **Working Conditions and Power Consumption of Jaw Crushers, Particularly for Large Aggregates.** BONWETSCH, A. *Mitteilung des Forschungs-institut für Maschinenwesen beim Baubetrieb* (5), 1933, Verein Deutsche Ingenieur Verlag, Berlin. An investigation of the power requirements of 23 jaw crushers. The main conclusions were: (1) The drive on primary crushers should be by two motors of relative power 2:1, the larger one for the starting load. (2) The power required bears a constant relation to the area of feed opening, and the energy consumed depends on the volume of rock crushed. Tables are given for these. Abstracted by Shergold, Road Research Laboratory, D.S.I.R., and reprinted from *Quarry Mgrs' J.*, 1947, **30** (10), 586–97. [P]

890. **Operational Characteristics and Stresses in Jaw Crushers with Particular Reference to Large Crushers.** BONWETSCH, A. *Quarry Mgrs' J.*, 1947, **30**, 586. The monograph comprises a theoretical discussion of the distribution of forces and stresses in crushers, together with associated experimental work carried out mainly on large double-toggle jaw crushers. The work includes direct measurements of starting torque wattmeter readings of power consumption and measurements (with a condenser gauge and oscillograph) of the variation of forces occurring in the pitman during crushing. It is divided into the following principal sections: classification; theoretical considerations; the starting process with primary crushers; operational characteristics of primary crushers, secondary crushers and granulators; the effect of operating conditions and rock type on power requirements; energy consumption; frictional characteristics; forces in the pitman; and protection against overload. The article referred to is itself an abstract of 35 000-word original. The main conclusions of the author with regard to frictional losses, and stress distribution, together with the effect of operating conditions on power requirements and energy consumption are included. [P]

891. **The Jaw-Crusher as a Primary Breaker.** BUCHANAN, C. G. *Rock Prod.*, 1923, **26** (5), 75. Among general advantages of the jaw crusher may be mentioned: (1) it is accessible in every part; (2) all moving or wearing parts can be adjusted or replaced quickly if necessary; (3) it has a greater range of adjustment than the roll or gyratory crusher; (4) the openings of the jaws can be increased or diminished.

892. **Combination Crusher and Grinder.** CLARKE, V. E. *U.S. Pat.* 2318290, 1940. In a jaw crusher with low pivot (Dodge type) the linings of both jaws are extended to curve around the pivot, forming a space where the material is ground after crushing. The object is for the mill to receive relatively large lumps of coal and to reduce them to any desired degree of fineness in one operation.

893. **Jaw Crusher with Impact Action.** EDWARDS, F. H. *Mine & Quarry Engng*, 1945, **10**, 152. A jaw-type crusher consists of an anvil pivoted on a stationary shaft and held up to its work by back-screws which can be adjusted to regulate the crusher opening.

The hammer block is suspended by two links hanging from cross spindles in the frame, and the tail of the hammer block is connected to one end of a pair of toggle levers, anchored to the frame, and driven by an eccentric cam. The short and uniform throw of the hammer is claimed to secure fine control of the finished product and to reduce power consumption to a minimum. *See also* Edwards, F. H., *Rock Prod.*, 1944, **47**, 80.

894. **On the Surface Form of the Crushing Plates of Jaw Crushers.** ERMOLAEV, P. B. *Mech. Constr., Moscow* (*Mekhan. Stroit.*), 1955 (3), 20–4; translation available at D.S.I.R.; ref. C.T.S. 144, price 8*s*. 0*d*. net.

895. **A Review of Certain Unit Processes in the Reduction of Materials.** FARRANT, J. C. *Trans. Instn chem. Engrs, Lond.*, 1940, **18**, 56. The design of jaw crushers should be such that the major wear is above the point of discharge, and the rate of fall of the particles is sufficiently low to ensure that they shall be nipped at least once while the jaws are in the closed position.

896. **Performance of Jaw Crushers.** GAULDIE, K. *Engineering, Lond.*, Oct. 1953, **176** (4576/7), 456–8, 485–6. A theoretical investigation into the effects on quantity and quality of output of the shape, disposition, dimensions and speed of the crusher jaws, and of the mean densities of the material passing down. Expressions are derived from geometrical analysis of the movement of the material and for calculation of output. It is shown how output may be reduced by excessive speed and increased by an appropriate length of the parallel output zone, and how the necessity or otherwise of controlled feed can be deduced. [P]

897. **Jaw Crusher Capacities (Blake Type).** GIESKING, D. H. *Trans. Amer. Inst. min. (metall.) Engrs*, 1949, **184**, 239–46; 1950, **187**, 568. Recording instruments were connected with crushers and data were obtained that led to the induction of the following equation: $C=f.d.w.y.t.n.a.r$, where C is capacity in short ton/h; f is the feed factor and is dependent on the presence of fines in the feed and the surface character of the jaw plates used; d is the bulk density of the product (lb/cu. ft); w is the width (in.) of the crushing chamber; y is open side setting of the crusher (in.); t is the length (in.) of stroke at the lower tip of the swing jaw plate; n is the crushing strokes per min.; a is the nip angle factor, it is unity for 26° and 3% greater for each degree less; and r is the realization factor. Values of f are tabulated and values of r are given in graphical form. The equation is also applicable to single-toggle jaw crushers. 8 figs. (*See* Ahlmann, who found that output is *not* proportional to throw.) [P]

898. **Jaw Crusher Capacities, Blake and Single-Toggle or Overhead Excentric Types.** GIESKING, D. H. *Min. Engng, N.Y.*, 1951, 3 (11), 971–4. The paper is an analysis of capacity characteristics of jaw crushers, and no other features are dealt with. The analysis is illustrated by force diagrams and jaw design diagrams and tabulated data on the effect of feed characteristics on output. In the Blake type crusher, capacity did not vary with crushability of feed, but with single-toggle crusher a trend to a relationship was observed. A capacity equation is given for the two types of crusher. [P]

899. **Selecting a Crusher.** GORMAN, W. *Min. Congr. J., Wash.*, 1940, **26**, 68; *Ceramic Abstr.*, 1940, **19**, 195. Jaw crushers are usually used as primary crushers as they have a larger receiving opening for the same capacity. With a coarse feed, a straight jaw plate should be used; with only a little coarse feed, non-choking surfaces should be used; they wear more uniformly. The Blake type jaw crusher has a larger capacity and the most leverage on the largest rock. The Dodge type is the reverse of this, but produces a more uniformly sized product. The single toggle produces a downward thrust on the material and has a large capacity.

900. **Reduce Capital Outlay and Operating Cost with Welded-Base Jaw Crushers.** HEER, R. W. and ECKLEY, W. A. *Concrete, N.Y.* (Cement Mill Ed.), 1943, **51**, 171–3; *Ceramic Abstr.*, 1943, **22**, 158.

901. **Crushing and Fragmentation of Rocks. II. Influence of Crusher Stroke on the**

Particle Size of Materials. JOISEL, A. *Ann. Inst. Bâtim.* (New Series), 1948, 51/56, No. 52 (with summary in English); *Muck Shift. publ. Wks*, 1949, 7 (5), 191. From this study, undertaken to clarify some of the results obtained previously, it is concluded that the crusher stroke (and the effect on reduction of two cylinder crushers) has an important bearing on the particle size of the product. Exaggerated enlargement of the stroke produces a considerably higher percentage of fines and an increase in compressive stress; this results in greater damage to the surface of the crusher jaws. It is therefore advisable to avoid setting the crusher jaws too far apart to obviate wasteful operation and undue maintenance costs.

902. **Crushing and Fragmentation of Rocks. III. The Influence of the Teeth of the Crushers.** JOISEL, A. *Ann. Inst. Bâtim.* (New Series). 1950, No. 122; Abstract in *Build. Sci. Abstr.*, 1950, **23** (3), 296. It is customary for the jaws of crushers to be toothed, although the teeth wear down rather rapidly so that the crushing surface becomes uneven. The effect of the teeth and of their subsequent wear on the shape and grading of the crushed product and on the efficiency of the crusher is investigated by means of an experimental study using gneiss as the material for crushing. The results indicate that the toothed jaws of crushers do not really improve either the size or the shape of the product, and that such crushers require as much power as those with plain jaws. whilst their output is only slightly greater (not more than 10%). Moreover, the wear on crushers, whose teeth are inclined to the direction of pressure, is very considerable and more rapid than on plain crushers. That teeth are unnecessary on crushers is shown by the fact that the grading and shape of the material crushed in gyratory crushers without teeth are identical with the grading and shape of similar products from toothed crushers, other experimental conditions being the same. (*See* Anon., *Pierres et Min.*, 1934, **6** (61/62), 959–70. Worn teeth should be replaced to achieve a cubic product.)

903. **Design of a New Jaw Crusher Avoids Toggles.** KOSTER, J. *Engng Min. J.*, 1934, **135** (12), 580. Describes double-jaw crusher of Blake type, with spring-mounted stationary jaw as a protection against tramp steel, crushing jaws shaped to equalize crushing from feed end to discharge, large capacity, and uniform product.

904. **Physics of the Crushing Process and Mechanics of Jaw Crushers.** LEVENSON, L. B. *Mech. Constr., Moscow* (*Mekhan. Stroit.*), 1954, **11** (1), 27–31. A critical review is presented and the recent hypothesis of T. I. Mukha is discussed.

905. **Improvements in Jaw Crushers.** LINKER, G. *Brit. Pat.*, 673912, 1952. A jaw crusher has two pivoted crushing jaws, kept oscillating about their pivots by rotating wheels journalled on the free ends of the jaws, both with unbalanced weights, one being displaced 180° in phase relative to the other.

906. **Parallel Jaw Crusher with Lubricating Means within the Jaw.** MEINHARDT, M. E. *U.S. Pat.* 2505132, 1950. An improvement in the technique of lubrication is described.

907. **Selecting the Crusher.** MICHAELSON, S. B. *Engng Min. J.*, 1940, **141**, 41; *Ceramic Abstr.*, 1941, **20**, 99. A general account of the factors which govern the performance of jaw crushers.

908. **Steels for Refractory and Heavy Clay Industries.** MILES, G. W. and KEITH, W. B. *Edg. Allen News*, 1954, **33** (379), 1–4; (380), 28–30. Austenitic steel has long been used for the manufacture of jaw crushers and other heavy-duty breakers. A table presents the behaviour of several steels when used for jaw crusher service. [P]

909. **Comparative Laboratory Tests with Jaw Crushers.** MORTSELL, S. *Jernkontor. Ann.*, 1951, **135** (9), 529–52. A laboratory Dodge-type crusher and a full-scale Blake-type crusher were used. The conclusions are set out in four parts. [P]

910. **An Investigation of Crushers, with Special Reference to Particle Shape.** ROSSLEIN,

D. *Quarry Mgrs' J.*, 1947, **30** (4), 207–22. An abridged translation from the German. *See under* Aggregates.

911. **Dry Roll Bearings.** ROUBAL, A. J. *Machine Design*, June 1953, **25**, 131–3. For heavy duty toggle mechanisms, these provide long life and require no lubrication. The action of the bearing is described (rolling instead of sliding contact) and well illustrated.

912. **A Double Action Crusher.** RUHL, H. *Z. Erzbergb. Metallhüttenw.*, 1955, **8** (4), 192–3. A new crusher with two moving jaws and a vertical gap is described and illustrated by diagrams. The jaw surfaces are plane except for the exit curves. The lower parts of the jaws are opened and closed by rapidly revolving eccentrics. Rapid delivery is attained. A jaw opening of 150 mm will take a 120-mm size feed. The output can be varied from 15 mm to 2 mm in open circuit and down to 2 mm in closed circuit.

913. **Jaw Crushing with Side Thrust Absorbing Bearings.** RUMPEL, H. H. *U.S. Pat.* 2598942, 1952. The crusher has a fixed jaw; there is a thrust bearing between the toggle link and the eccentric that operates it.

914. **Principles of Comminution. 1. Size Distribution and Surface Calculations.** SCHUMANN, R. *Tech. Publ. Amer. Inst. Min. Engrs.*, No. 1189, 1940. Logarithmic Probability method of plotting size distribution. Application to product of jaw crushing test, where a 6·7-kg sample of 1–1½-in. quartz thoroughly cleaned from dust was crushed in a laboratory jaw crusher set at ⅜ in., water being used all the time. The relation of measured distribution and surface to the previous formulae is discussed, and it is thought from the results that the small proportion of the product below about 3 microns (0·13%) may conceivably account for most of the surface. Results are presented graphically. 11 pp., 13 refs.

915. **Jaw Crusher.** SHELTON, H. J. *U.S. Pat.* 2566583, 1951. A jaw crusher with one fixed jaw, the position of the movable jaw being adjusted by shims between it and the back support.

916. **Research on Jaw Granulators.** SHERGOLD, F. A. (Road Research Laboratory, D.S.I.R.). *Bull. Ass. int. Route*, 1954, No. 138. Seven types of rock were investigated. Of the preferred sizes for road dressing, ¾, ½ and ⅜ in. 40% of ¾–½in. size could be obtained, but only about 11% of each of the sizes ½–⅜ in. and ⅜–¼ in.; and the proportions of these lower sizes could not be substantially increased whatever the jaw setting. Curves show that the major size component of each crushing lay between the open and closed jaw settings. [P]

917. **Jaw Type Crusher.** TRAYLOR, S. W. Jr. *U.S. Pat.* 2591639, 1952. Describes a means whereby the moment of the crushing force exerted upon the fixed jaw by the movable jaw is greater than the force moment exerted by the movable jaw drive means about the fixed jaw pivot.

JAW CRUSHER WITH FLOATING MEMBER

918. **Jaw Crusher.** BARBER, H. L. and SELLARS, G. L. *U.S. Pat.* 2626759, 1953. The crusher consists of two opposed elements with a third massive element oscillating between them.

GYRATORY CRUSHERS

919. **How to Select a Gyratory Crusher for your Job.** ANON. *Brick Clay Rec.*, 1952, **121** (6), 77–8. Useful hints on gyratory crusher selection are given. A method is described for calculating the horsepower requirements from a knowledge of the hardness, toughness and specific gravity of the material and the ratio of product and product size. Graphical representation of performance data. The crushing resistance of the feed must be determined by impact tests or otherwise approximated. [P]

920. **Disintegrators for Crushing Saggars and Firebricks.** ANON. *Brick Pott. Tr. J.*, 1922, **30**, 232. A description (2 illustrations) of the 'Lightning Crusher and Pulverizer'.

921. **Forced Lubrication of Gyratory Crushers.** ANON. *Mine & Quarry Engng*, 1941, **6**, 310.

922. **Stone Crushers.** ANON. *Mine & Quarry Engng*, 1942, **7** (11), 268. The duty of the gyratory crusher is limited and requires more careful selection than that for the jaw crusher. It is best used for reducing the oversize pieces in a parcel of material, and also for the production of 'smalls'. The machine must be fed with clean stone or stone wherein the amount of dirt and clay is kept down to the lowest practicable figure; the product of this machine is more true to size than that of the jaw crusher. There are two types of gyratory crusher; the standard type and the 'low head' type, the difference in the two heights being considerable. They are mostly belt- or bevel-gears, but a later type machine is driven without gearing, by a vertical motor coupled direct to the vertical shaft.

923. **Plant and Equipment.** *Mine & Quarry Engng*, July 1943, 243; *Engineer, Lond.*, 15 May 1953, 690. Description and illustrations of the Esch-Werke K.G. of Duisberg large gyratory crusher, exhibited at the Hanover Fair. 1000 ton/h, dealing with pieces of rock 80×60×40 in. Height 26 ft, diameter 16 ft and driven by a 225-h.p. 1500-rev/min motor. Cone gyrates at 125 per min. Bearings are dustproof, the cone does not start until lubrication pumps are running, and feeding takes place nearly all round the top. The main development is that the crusher can be started with the mouth full by means of a heavy load starting gearing. The operation is automatic and the machine switches off in case of possible damage. Total weight 165 tons. *See also* Molling, H. A., *Progressus*, 1953, **5** (E5), 22.

924. **Gyratory Type Crusher.** ANON. *New Equipment Digest*, 1948, **13** (4), 13; *Ceramic Abstr.*, 1948, **31**, 159. The gyratory action of the Kue-Ken Gyracone crusher permits crushing by pressure only, without rubbing or sliding.

925. **Study of Crusher Types.** ANON. *Pierres et Min.*, 1934, **6** (61/62), 959–70. A comparison of Jaw v. Gyratory Crushers. *See under* Jaw Crushers.

926. **The Superior Crusher.** ALLIS CHALMERS MANUFACTURING CO. *Min. Engng, N.Y.*, 1951, **190**, 142. This crusher is announced as having a cast steel spider hub which permits raising of the shaft as wear progresses on the manganese steel mantle. Weight has been reduced.

927. **Improvements Relating to Gyratory Crushers.** ALLIS CHALMERS MANUFACTURING CO. *Brit. Pat.* 721014, 1953/54. A mechanism is provided so that the feed plate on which the feed falls does not change its distance from the feed shaft every time the main shaft suffers vertical displacement, such as when freeing tramp iron.

928. **Gyratory Crusher.** BECKER, G. D., ALLIS CHALMERS MANUFACTURING CO. *U.S. Pat.* 2667309, 1954. The improvement embodies a means for preventing the rising of the inner member at unusual conditions of crushing.

929. **Bell Shaped Heads and Concaves for Gyratory Crushers.** BERNHARD, R. *Min. & Metall., N.Y.*, 1932, **13**, 107–8. The principal improvements in the last decade are the increase in size of machines and sealing the eccentric mechanism to exclude grit. Illustration of the fine reduction gyratory crusher. The head has a greater flair.

930. **Pneumatic Release for Gyratory Crushers.** BJARME, J. A. *U.S. Pat.* 2680571, 1954. Air pressure acting on pistons results in lifting the bowl and so releasing the obstruction, which falls.

931. **Unit Operations.** BROWN, G. G. AND ASSOCIATES. 1950, Wiley and Sons, New York. On p. 30 is an illustration of a parallel pinch crusher. An eccentric sleeve on the vertical axis gives a pinching action by the cone, the latter being similar to that of a gyratory crusher.

932. **Improvements in Gyratory Crushers.** BURGESS, A. F. *Brit. Pat.* 646795, 1947/50. A special bearing arrangement for a gyratory crusher is described.

933. **A Gearless, Gyratory Crusher.** CAVANAGH, W. J. *Rock Prod.*, 1923, **26** (5), 97. An illustrated account is given of a gyratory crusher, in which the gears are replaced by a pulley.

934. **Selecting a Crusher.** GORMAN, W. *Min. Congr. J., Wash.*, 1940, **26**, 68; *Ceramic Abstr.*, 1940, **19**, 195. Gyratory crushers have a greater capacity for reducing material to a given size than jaw crushers of equal receiving openings.

935. **Output of Gyratory Crushers.** GAULDIE, K. *Engineering, Lond.*, 1954, **177**, 557–9. Formulae are developed from the characteristics and dimensions of the crusher, for calculating output. Graphs are presented showing how output is affected by the settings of the gap, by altering the base angle of the cone and by frictional characteristics of the material. Optimum speeds and cone angles are indicated. The mathematical treatment is based on the assumption of similarity of the gap to a large number of triangular jaw crushers. An example illustrates the application of the equations derived. [P]

936. **Gyratory Crusher Trouble.** HESS, J. B. *Engng Min. J.*, 1942, **143** (9), 67; *Mine & Quarry Engng*, 1943, **8**, 48. An account is given of trouble that developed, after 8 years' satisfactory service, in a gyratory crusher capable of crushing 24–30 tons of one-man stone per hour, working about 3000 hours a year. About 8 years ago, the eccentric froze to its cast-iron bushing, sheared off 4 zinc keys and rotated the entire bushing, thus wearing a very irregular surface in the main body of the foundation casting. The means of avoiding the fault are described.

937. **Investigations into the Product of Crushing Machines.** KOLB, H. *TonindustrZtg*, 1936, **60** (6), 61–3; (9), 112–14. Performance data for a gyratory machine are presented in a series of eleven curves for the crushing of rock for cement manufacture, showing the influence of the various governing factors. [P]

938. **Gyratory Crusher.** KUENEMAN, J. R. and D. *Brit. Pat.* 647793, 1950. Improved design of the moving parts as well as an effective dustshield for the bearings; and improved lubrication are claimed.

939. **Test on a Gyratory Crusher.** MAMILLAN, M. M. *Ann. Inst. Bâtim.*, 1953, (72), 1135–56. A translation may be consulted at D.S.I.R.; Ref., Records Section, 21588. The tests performed on a gyratory crusher lead to the following conclusions: (1) A diminution of the rotating velocity below the theoretical optimum velocity entails (a) an increase of power per ton product, (b) a decrease of output, (c) an increase of fines and flat particles. (2) If the reduction ratio is increased, (a) the fines and power consumed increase, (b) the shape of the fragments is improved, (c) the output is reduced. (3) The process of presieving the feed entails the following changes: (a) the percentage of fines is reduced, (b) the product obtained is more selective, (c) the output increases, (d) power required is decreased. (4) If rock resistance increases and other conditions remain constant, (a) the shape of product is less cubical, (b) the size of product is larger, (c) the fines are decreased, fragmentation is more selective, (d) output and energy per ton increase.

The mode of action of the gyratory crusher is described and illustrated. The mechanism of descent of product through the crusher is analysed graphically and algebraically. Geometrical characteristics of the product are defined. The results of tests with soft limestone, siliceous limestone, lithographic limestone and granite are presented in four main tables and 30 graphs. [P]

940. **Improvements Relating to Gyratory Crushers.** MORGARDHAMMARS, MEKANISKA WERKSTADS, AKTIEBOLAG, SWEDEN. *Brit. Pat.* 720942, 1952/54. The improvement concerns the displacing of the upper bearing of the crusher shaft.

941. **Electrical Control of Gyratory Crushers.** PATTERSON, W. H. and GERG, R.

Pit & Quarry, 1953, **45** (12), 70–3. Fluctuations in electrical load for gyratory and jaw crushers are compared: the flywheel reduces overload in jaw crusher. Steps for efficient operation and auxiliary equipment for overload protection are discussed. 7 figs. [P]

942. **Gyratory Crushers as Primary Breakers.** ROBERTS, W. J. *Rock Prod.*, 1923, **26** (5), 77. The advantages of gyratory crushers over other types are pointed out.

943. **A New Type of Gyratory Crusher.** RUMPEL, H. H. *U.S. Pat.* 2590795, 1952. Specifies an improved bearing assembly, improved drive and improved mounting.

944. **Adjustment Structure for Concaves of Gyratory Crushers.** RUMPEL, H. H. *U.S. Pat.* 2668015, 1954. The invention is the provision of a simple dependable mechanism for effecting relative adjustment of the fixed and gyrating members.

945. **Primary Crushing. Progress Rept. No. 1.** SHEPPARD, M. and WITHEROW, C. M. *Rep. Invest. U.S. Bur. Min.*, No. 3377, 1938. 11 pp. An investigation into the relationship between size gradation of feed and product when crushing limestone in a *gyratory* and a *single roll* crusher. Results are embodied in 14 graphs and 6 tables. A long summary of results is appended. [P]

GYRATORY CRUSHER WITH FLOATING MEMBER

946. **Gyratory Crusher Having a Floating Ring.** TRAYLOR, S. W. Jr. *U.S. Pat.* 2498774, 1950. A plurality of crushing spaces is provided, and undue cocking of the ring is prevented. It is claimed that choking is prevented by suitable shaping of the ring.

GYRATORY CRUSHER WITH DOUBLE ROTOR

947. **Gyratory Crusher.** SPOHN, J. H. *U.S. Pat.* 2188666, 1937. A vertical shaft rotates and its upper end gyrates. A double (upright and inverted) bowl cooperates with a pestle and an attrition rotor respectively. The rotor gyrates in the upper bowl, the crushed material drops through the base opening to the attrition rotor which bears on the spherical surface of the lower (inverted bowl). The object is to facilitate fine grinding operations. The drive is by wheel attached to the upper outer end of the vertical shaft.

CONE CRUSHERS

948. **Exploitation of Low Grade Ores in U.S.A.** *O.E.E.C. Technical Assistance Mission*, No. 228, 1954. O.E.E.C., Paris. Obtainable from H.M. Stationery Office. Chap. IV, Hydrocone Crusher. For the secondary and third crushing stage, the relatively new hydrocone crusher is beginning to compete with the Symons cone crushers, although the larger plants still seem to prefer the latter type. Usually the crushing is done in open circuit even in the final stage. The hydrocone crusher is provided with a hydraulic instead of a spring release mechanism.

949. **Symons Crusher in the Ceramic Industry and the Universal Grinding Plant.** KIRCHHOFF. *Ber. dtsch. keram. Ges.*, 1941, **22**, 135; *Ceramic Abstr.*, 1941, **20**, 222. The Symons conical crusher was applied to ceramic materials and, after modification an output of 20% of particles under 5 mm was obtained. The product of the Symons granulator, as it is called, is splintery with sharp angles, which is a great advantage in the ceramic industry.

950. **Gyratory Crusher (Hydrocone Crusher).** MCGREW, B. *Rock Prod.*, 1950, **53** (12), 129. This is a fine reduction crusher whose plates are convex. It approaches the cone crusher in action. It rates with the Newhouse crusher of somewhat similar design as a high-speed crusher.

951. **Symons Crusher.** MITTAG, C. *Ber. dtsch. keram. Ges.*, 1941, **22**, 130–5; *Ceramic Abstr.*, 1941, **20**, 222. For 30 years Symons Bros. worked on the improvement of the

circular crusher, but not until 1928, with the Symons crusher, did they follow any fundamentally new idea. Observing that when stone is broken by blows of a hammer the product is more uniform than when broken by pressure, Symons Bros. designed their crusher so that the pieces of stone are subjected to repeated blows but cannot fall from the crusher until they have attained the desired size.

952. **New Symons Cone Crushers.** NORDBERG MANUFACTURING Co. (Milwaukee). *Mine & Quarry Engng*, 1941, **6**, 197. A new two-foot short head crusher has been developed for a limited output demand. The same fineness ($\frac{1}{8}$ in.) of output as for larger crushers is claimed, and the design is similar. Table of performance data is given.

953. **Improvements Relating to Crushers and the Like.** NORDBERG MANUFACTURING Co. (Milwaukee). *Brit. Pat.* 720528, 1952/54. A feed plate is mounted at the top of the gyrating member (the lower member) and by revolving at a speed different from that of the eccentric, it distributes the coarse and fine feed evenly to the crusher gap, and so avoids the segregation which normally occurs.

954. **Design Development of Crushing Cavities.** ZOERB, H. M. *Min. Engng, N.Y.*, 1953, **5** (6), 603–5; *Rock Prod.*, 1953, **56** (10), 101–4. The paper traces the development of the crushing cavity design in Symons cone crushers to attain maximum liner utilization. Wear rates are analysed and compared, and design changes are illustrated by drawings. Metal thickness is placed where most work is done. The wear of the liners had the effect of lengthening the cavity. Design changes led also to economies in power and maintenance. Diagrams of various profiles are presented. Much more investigation is needed.

955. **Crushing Manganese Ores with Cone Type Crushers.** ZUBAREV, S. N. and DZHINCHELASKIVI, K. P. *Min. J. Spb.* (*Gornyi Zhurnal*), 1950 (2), 38–9 Performance results are summarized in six tables. [P]

GYRASPHERE

956. **Rock Crusher Performance.** ANON. *Chem. and Process Engng*, 1953, **34** (10), 331–2. The Gyrasphere works on the principle of an inverted pestle and mortar. There is a large feed opening and the design permits unobstructed and unlimited feed. A feature is the resistance to liner wear, even when crushing very abrasive materials. In this Pegson gyrasphere, the concave and mantle have been replaced only after the reduction of 17 000 tons of aggregate in 18 months. Fines have been reduced by 50% over previous equipment. Sizes are 24, 36 and 48 in.

MISCELLANEOUS BREAKERS

957. **Toothed Cone Mill.** *Engng Min. J.*, 1953 (9), 54. A grinding mill consisting of a fluted vertical cone with coarse teeth at the top and fine teeth at the lower part. The top opens for cleaning. Capacities one to 30 ton/h.

958. **Grinding, Crushing, Mixing and Like Mills.** SEAMAN, C. J., BRINJES & GOODWIN, LTD. *Engl. Pat.* 209857, 1922. Cone mills are constructed with two truncated conical members in contact with each other and independently driven. The members may be side by side or one inside the other. The material emerges at the large ends of the cones.

Fine Reduction

STAMP MILLS

959. **De Re Metallica.** AGRICOLA (GEORGIUS). 1950, Dover Publications, New York. 638 pp. Includes descriptions with wood-cuts of stamp mills, their operation and uses; powered by waterwheels and by draft animals.

960. **Investigations in Ore Milling to Ascertain the Heat Developed in Crushing (in Stamp Mills).** COOK, J. *Trans. Instn Min. Metall., Lond.*, 1914–15, **24**, 234–51. *See* No. 49.

961. **Mechanical Efficiency in Crushing.** DEL MAR, A. *Engng Min. J.*, 1912, **94**, 1129–34. *See* No. 54.

962. **Tube Milling (Ball and Pebble Mills).** DEL MAR, A. McGraw-Hill Book Co., New York, 1917. 145 pp. A treatise on the practical application of the tube mill to metallurgical problems. A series of flow sheets is given for stamp mill operation with and without tube mills to follow. The stamp mill is still with us for amalgamating and for a medium-size product, and in combination with the cylindrical tube mill, for cyanide treatment of a slime. Second is the popularity of the conical mill for a product up to 90 mesh, in competition with a tube mill of large diameter and short length, in circuit with a classifier. Third is the deserved popularity of the cylindrical tube mill with varying diameter and length according to the size of feed. [P]

963. **Zerkleinerungs Vorrichtung und Mahlanlagung.** (Grinding Equipment and Installation.) NASKE, C. 1921, Verlag, Otto Spamer, Leipzig. 330 pp., 415 figs. Contains a chapter on stamp mills.

964. **The First Stamp Mills in English History.** SHUBERT, H. R. *J. Iron St. Inst.*, Nov. 1947, **157**, 343–4. The vertical stamp mill working in a mortar dates back to A.D. 1500 and is one of the oldest types. They were first introduced into England from Germany where skill in mining had reached a very high standard. Illustrations, 11 historical references.

965. **Gold Metallurgy in the Witwatersrand.** STITT, D. D. 1949, Transvaal Chamber of Mines, Johannesburg. Chap. 2, pp. 39–55. Stamp Milling. Includes illustrations, drawings of mill and components, tables of dimensions and a table of comparative performance of stamp mills at different mines. [P]

966. **A Text-book of Ore Dressing.** TRUSCOTT, S. J. 1923, Macmillan & Co., Ltd., London. In chapter three is given an illustrated description of various types of stamp mill.

967. **Stamp Mills.** WAGONER, L. *Trans. Tech. Soc. Pacific Coast*, 1886, **3**, p. 45. Discusses power used in crushing with stamps and the Tustin Mill, with data on surface area of the products of both mills. [P]

CASCADE TYPE MILLS

968. **Exploitation of Low Grade Ores in U.S.A.** *O.E.E.C. Technical Assistance Mission*, No. 228, 1954. *O.E.E.C., Paris.* Obtainable from H.M. Stationery Office. Chapter IV. A growing interest in cascade type mills has been noticed. It is a dry combined crushing-grinding unit operating in closed circuit with an air classification system and capable of taking −18-in. material and reducing it to −325 mesh in a single operation, or else capable of producing a product in the 10-mesh range. The

material itself may be used as the crushing medium or else metal balls can be used. As there is only one unit, capital costs and floor space are low per ton of product. Maintenance cost is low when compared with that of other crushers and grinders, and efficiency is high. It is claimed that the aerofall mill gives a more uniform grind with less oversize, and lower slime than other equipment. Quotes *Trans. Canad. Min. Inst. (Inst. Min. Metall.)*, **53**, 1950, 445–51.

969. **Classification in Witwatersrand Mills.** BATES, B. R. *Trans. Amer. Inst. min. (metall.) Engrs*, 1926, **73**. Classification in milling operations at South African Mines. The author's work confirms the advantage of preliminary crushing in a *cascade mill*.

970. **Aerofall Mill Finds Increasing Application.** BEALS, R. A. *Min. Engng, N.Y.*, 1955, **7** (9), 842–5. The materials for which the Aerofall mill is now being applied are tabulated with typical performance data. The 17-ft diameter mill is illustrated together with plant layout for recovery of oversize. It is claimed that the mill can reduce run of mine gold ore, for instance, to the final size for the cyanide plant, thus eliminating primary and secondary crushers and grinders. The history beginning at 1930 is briefly described. Material containing 4% moisture can be successfully reduced. [P]

971. **A Review of Certain Unit Processes in the Reduction of Materials.** FARRANT, J. C. *Trans. Instn Chem. Engrs, Lond.*, 1940, **18**, 56. Included in a general discussion on reduction equipment is a brief description of a cascade mill. This mill consists of a built-up wheel approximately 30 ft diameter. Around the periphery there are buckets which carry the coarse mineral to a point where the buckets empty and shower the contents on to rigid breaker bars, this impact shattering the falling pieces. The wheel is partially submerged in water which carries away the finished product; the coarser fractions are carried round by the buckets together with the incoming feed. The feature of the unit is the large range of reduction, from 10-in. lumps to 60 mesh in one operation.

972. **A Progress Report on the Aerofall Mill.** FLECK, R. G. and DUROCHER, R. E. *Min. Congr. J., Wash.*, 1955, **41** (12), 52–4. Improved performance and recovery comparison with those of the rod mill with martite (a mixture of haematite and magnetite). The product at −10 mesh is transferred to a series of Humphrey spirals. The feed to the Aerofall mill is from a 54-in. gyratory crusher set at 8 in., the proportion of coarse to fine feed to the mill not being critical. Diagram and flow sheet for the 17-ft mill is shown. [P]

973. **The Hadsel Mill.** HALL, R. G. *Trans. Amer. Inst. min. (metall.) Engrs*, 1935, **112**, 15–24. The wheel is 24 ft in diameter and by flights lifts the rock until it falls on to hard metal plates disposed near the bottom of the interior. About a 90° arc was immersed in a tank. The lifting flights were as wide as the wheel (3 ft), and were 2 ft deep. The material overflowed into the tank and was carried away to be classified. The rock was lifted 259 times before being finally ground, and the daily capacity was 250 tons. A table embodying the dimensions, etc., of 16 sizes of Hardinge-Hadsel mill are given. The principle has been demonstrated as sound. Ordinary run of mine ore can be reduced to flotation or cyaniding size in one operation with closed circuit and classifier. The advantages are: (1) simplicity, (2) saving in cost, (3) saving in power with improvement in load factor, (4) saving in wear. The Hadsel mill was regarded as a forward step. Tables of data are given.

974. **Making Rock Grind Itself.** HARDINGE, H. *Engng Min. J.*, 1955, **156** (6), 84–90. The advantages of autogenous grinding are described and a history of self-grinding mills presented. The 1934 Hardinge-Hadsel mill 24 ft diameter is illustrated and its capabilities described. The segregation of size which occurred in this mill has been overcome in the modern Hardinge Cascade mill by use of flat cone-shaped ends, while the frequent failure to shatter a particular 'critical' size on the breaker plates is overcome by the use of a small quantity of balls of appropriate size in the crusher. It remains for the courageous operator to avoid a repetition of errors made in the past.

975. **Application of Air to Asbestos Milling at the New Jeffry Mill of the Canadian Johns-Mansville Co., Ltd., Asbestos, Quebec.** Rosovsky, H. *Trans. Canad. Min. Inst.* (*Inst. Min. Metall.*), 1955, **58**, 268–77. A gravity impact mill is used. *See under* Asbestos.

976. **The Aerofall Mill in the Milling of Industrial Materials.** Weston, D. *Trans. Canad. Min. Inst.* (*Inst. Min. Metall.*), 1950, **53**, 445–51. A tumbling mill is described in which larger rock is fed to cause its own comminution and sometimes with balls 5–$2\frac{1}{2}$ in. diameter at about $2\frac{1}{2}$% by volume. An advance in one stage yields is claimed. A fine product, −325 mesh, is formed with the coarse material. The author believes that size reduction occurs in zones.

977. **Material Reduction Mill.** Weston, D. *U.S. Pat.* 2555171; 1951; *Off. Gaz. U.S. Pat. Off.*, 1951, **646** (5), 1662. A mill, capable of reducing run-of-mine size feed material to a comparatively fine state in a single stage, is described. The drum is very short compared to its diameter, and is provided with 'squirrel cage' bars to prevent slippage. Crushing is by impact of the particles on themselves or by attrition. An air current carries out fines for further classification.

978. **Drum (Tumbling) Mills.** Weston, D. *French Pat.*, 1053784, 1950/54; *Brit. Pat.* 632532, 1947. The diameter of the mill is much greater than the length, and segregation of sizes is avoided by oblique members fitted on the end plates of the drum so as to direct the falling material to the centre. Like the mill quoted in the British Patent, flights are fitted to the periphery.

BALL, PEBBLE AND TUBE MILLS: EQUIPMENT

979. **Mechanics of the Compound Grinding Mill.** Anon. *Cement and Lime Manuf.*, 1945, **18**, 23–30. The principle, and design factors (speed, dimensions, mill and ball charge, power consumption, etc.) of the compound tube clinker mill are discussed in detail.

980. **A Multiple Ball Mill.** Anon. *Chem. Age, Lond.*, 20 Aug. 1954, 489. A U.S. firm supplies a machine in which four ball mill units are mounted on trunnions attached to a cylindrical frame and attached by chain to the stationary central shaft. On rotation, by the motion induced, the balls are kept sliding in contact with each other and with the walls. Maximum fineness can be attained with TiO_2 by 20 minutes' grinding.

981. **Grinding and Mixing.** *Chem. Age, Lond.*, 5 Feb. 1955, 393. A Stoke-on-Trent firm make a double duty mill and mixer, one at each end of the shaft. A shaper, polisher or churning adapter can be fitted.

982. **A New Ball Mill.** Anon. *Chem. Age, Lond.*, 3 June 1955, 1428. A Stoke-on-Trent firm announce the Mark II mill (10-gallon capacity as against the 10-pint Mark I mill). It is capable of grinding and dispersing material such as dyes, carbon black, calcined alumina in one-tenth the time taken by the conventional ball mill. The four jars are mounted in a container on a vertical shaft while the jars are rotated in the opposite direction, thus giving a high centrifugal force. The machine can be run on full production during practically the whole of the working period due to avoiding the necessity of cleaning.

983. **Novel Ball Mill Design.** *Chem. Engng*, 1954, **61** (9), 258. Crusher bars, spaced around the interior drum wall, are the novel features of the new design. The charge consists of 5-in. balls (instead of balls of varying diameter, occupying 3% of total mill volume. Total charge occupies 30% instead of 45–50%. Rotational speed is 85% of critical. Increased capacity, greater crushing action are claimed.

984. **Preliminary and Fine Grinding.** *Edg. Allen News*, 1953, **32**, 225–7; 1954, **33**, 3. The Stag Standard Combination Tube Mill is illustrated and described. It has peripheral screens, grinding and return plates, stepped. Castings of chromium steel. Austenitic steel is undesirable because under impact it spreads and distorts the plate.

985. **Tube Mill.** ANON. *Engineering, Lond.*, 1939, **148**, 681; *Ceramic Abstr.*, 1940, **19**, 121. The construction of a completely welded steel tube mill for grinding cement is described.

986. **Reduction Gears for Ball Mills.** ANON. *Engineering, Lond.*, 7 Jan. 1955, **179** (464), 28–29. Co-axial drive used in cement works. Developed in Sweden some years ago, B.T.H. have developed a compact double reduction co-axial gear box for a cement ball mill, using double helical gears. The gear box is designed to transmit 1200 h.p. with a speed reduction of 750 rev/min to 20·5 rev/min. There is a barring motor for low speeds for inspection. For flexibility there are two specially developed bonded rubber couplings, one on each end of the torque shaft, which will accommodate radial displacement and axial movement, and also out of alignment deflection on account of wear. Illustrations.

987. **Progress in Ball Mill Design.** ANON. *Engng & Boil. Ho. Rev.*, 1947, **62** (2), 50–5. Comparative ball mill tests to investigate the influence of barrel shape of a pulverizer mill upon the mill characteristics have been carried out in Russia by operating a cylindrical barrel mill with and without cone ends.

988. **Versatile Jar Mills.** ANON. *Laboratory*, 1953, **22** (5), 152–3. A laboratory three-tier jar mill equipment suitable for preparation of bacterial media and sample preparation. Details of available varieties and capacities of jars and pebble media are given.

989. **Ball Mill Drives.** ANON. *Mine & Quarry Engng*, June 1954, 279. A short description of the Barvue Mines, Ltd., Barraute, Quebec. Zinc ore ball mills (Hardinge Tricone mills), each grinding 1400 tons of ore in 24 hours from ½-in. to 60% −200 mesh. Each mill is powered by a 600-h.p. 1160-rev/min English Electric squirrel cage induction motor with fluid coupling by Fluidrive Engineering Co., Isleworth, Middlesex.

990. **Reclaiming Ball Mill Trunnions.** ANON. *Min. Congr. J., Wash.*, 1941, **27**, 60; *Ceramic Abstr.*, 1941, **20**, 242.

991. **From Open to Closed Circuit Grinding with Liquid Cyclones.** ANON. *Rock Prod.*, 1955, **56** (7), 62–6. *See under* Open v. Closed Circuit Grinding.

992. **Improvements Relating to Ball Mills.** EDGAR ALLEN & CO., LTD., and BARCHAM, E. F. *Brit. Pat.* 611885, 1946. Intermittent type ball mill. The sealing plate can be operated so that the mill can be emptied without interrupting the rotation, either with wet or dry grinding.

993. **Notes on Control of Feed to Ball Mills.** BALL, N. G. *Trans. Instn Min. Metall., Lond.*, 1940–1, **50**, 537.

994. **Progress in Crushing Techniques.** BATEL, W. *Umschau*, 1955, **55** (10), 297–300. A general review of modern improvements concerning impact mills, ball, concentra ball and vibrating ball mills. A final note on size distribution and on the equilibrium reached on continued fine grinding is given.

995. **Fine Grinding in Ball Mills.** BEKE, B. *Epitponyag.*, 1950, **2** (5/6), 84–8; *Hung. tech. Abstr.*, 1951, (3), 14. The use and operation of ball mills in the manufacture of Portland cement are described. The method of preparing milling diagrams is shown.

996. **Improvements Relating to Grinding and Pulverizing.** BRANT, E. H. *Brit. Pat.* 603036, 1945. An arrangement of the driving gear so that grinding or pulverizing containers of different sizes can be rotated on it.

997. **Ball Mill.** BRITISH REMA MANUFACTURING CO. and DAVIS, J. *Brit. Pat.* 603361, 1945. A circle of grinding plates is surrounded by a set of screening panels, located in a dust casing. A current of air is introduced which cleans the screens.

998. **Ball Mills and Patented Air Separating Equipment.** BRITISH REMA MANUFAC-

TURING Co., LTD. Publication No. 39, 1954, 11 pp. Descriptions, illustrations and drawings.

999. **Equipment and Design—Ball Mills.** BROWN, C. O. *Industr. Engng. Chem. (Industr.)*, 1948, **40** (11), 79A. Brief details are given of three new types of ball mill. In one the shell is almost 9 ft 7 in. in diameter, with a length of 32 ft; volume is 2655 cu. ft, of which two-thirds is in the first feed end; the 1 600 000 balls have a rolling grinding path of 75–80 ft with each revolution; an output of 2250 bags of cement per hour is claimed. Few details are given of another mill for batch grinding which is of small size and capacity, and has V-notch lifting bars on the inner shell to raise the travel of the balls and guide the end balls to the centre. A new development is a small ball mill which vibrates; it is used for batch grinding of pigments, etc. The action is that of beating to extend the particle into a thin sheet which is then broken into small pieces; this gives a very fine particle size of flake-like character. The principle is to increase the number of hammer blows by the balls in unit time. It is suitable for metal powders and other malleable materials.

1000. **How to Maintain Milling Equipment.** BROWN, H. M. *Brick Clay Rec.*, 1952, **121** (3), 58. Details are given of the steps and precautions to be taken when installing a new mill, both with regard to shell and the ball media.

1001. **Apparatus for Crushing and Separating Material.** BUTTNER WERKE, A. G. *Brit. Pat.* 686329, 1949. Air is introduced tangentially into the lower half of a ball mill over its whole length and then redirected upwards towards an outlet in the upper half. The air inlet is coupled with specially designed lifters. The size of particle can be accurately controlled and very small air velocities are sufficient and pressure loss is low. The whole is encased in a suitable stationary housing.

1002. **Improvements Relating to Pulverizing Apparatus.** CAMPBELL, J. G. *Brit. Pat.* 665398, 1949. An arrangement for obtaining a more desired distribution of particle size. It is a series of ball mills connected axially by sections of a gradually enlarging conical tube, which rotates with the ball mills, thus producing a series of independent grinding stages, the feed being at the narrower end of the connecting tube, and the ball size decreasing progressively.

1003. **Grinding Ball Classification. Its Effect on Capacity and Ball Migration.** CARMAN, C. MCA. *Rock Prod.*, June 1953, **56**, 106–9. Discusses the effect on grinding mill capacity and ball migration resulting from improved ball classification. The ball size distribution along the mill is analysed and presented diagrammatically and graphically, and assuming that a gradation of ball size from feed to outlet gives the most efficient performance, a means of attaining this gradation by ball classifying shell liners is suggested (the Carman patent) and illustrated.

1004. **Tube Mill.** CATLIN, A. W., BRADLEY PULVERISER CO. *U.S. Pat.* 1825333, 1931. A spiral conveyor is provided on the axis to return partly ground material to any desired point of the mill.

1005. **Silica Grinding.** CARWOOD, R. L. *Trans. Brit. Ceram. Soc.*, 1931, **30**, 295. At the Potters' Mining and Milling Co., U.S.A., a new grinding unit has been installed to replace the old batch mills, which are described. This new unit consists of a Patterson 8 × 10-ft. continuous feed and discharge ball mill, lined with Belgian silex, using French flint pebbles, and operated in conjunction with a 14-ft centrifugal air separator. Labour is about half that of batch mills, and the working conditions are improved by complete elimination of dust. [P]

1006. **The Manufacture of Heavy Clay Products.** COULHON, A. *Industr. Céramique*, 1948 (387), 133. In this part of the review the main features of ball mills are discussed. 1 fig.

1007. **Tube Milling (Ball and Pebble Mills).** DEL MAR, A. 1917, McGraw-Hill Book Co., New York. 145 pp. A treatise on the practical application of the tube mill to

metallurgical problems. A series of flow sheets is given for stamp mill operation with and without tube mills to follow. Second in popularity is the conical mill for a product up to 90 mesh, in competition with a tube mill of large diameter and short length, in circuit with a classifier. Third is the deserved popularity of the cylindrical mill with varying diameter and length according to the size of feed. [P]

1008. **The Tube Mill in Power Stations.** DOBREFF, *I. et al. Energie u. Tech.*, Jan. 1954, **4**, 37–40. Russian literature comparisons such as size of balls, speed of mill, ball load, are compared with German data. Russian mechanical loading and other efficiency devices are described. Grades of steel and alternate materials for the ball media and lining are discussed.

1009. **The Working Principles of Ball Mills for Grinding.** ENGELS, K. 1954, **8** (3/4), 102–7. The construction, performance and uses of the conventional, vibratory and centrifugal ball mills are described. *See under* Centrifugal and Vibratory Ball Mills.

1010. **Latest Developments in Fine Grinding.** GLOCKEMEIER, G. *Metall. u. Erz.*, 1922, **19**, 285. The principle of the tube mill, together with its later development, the shorter and wider ball mill, is first described. This is followed by a discussion of the various types of ball mills, including the ball mill with sieve, the overflow ball mill, Grondal mill, Hardinge mill, and the Marcy mill. The article closes with a short account of the rod mill, or Marathon mill, in which the balls are replaced by steel rods. There are a number of illustrations.

1011. **The Weight of Steel Balls in a Ball Mill.** GOW, A. M. *Engng Min. J.*, 1934, **134**, 203. An optimum of 300 lb/cu. ft steel balls, with 38% voids. Wear is independent of size.

1012. **Crushing and Grinding.** HARDINGE, H. *Min. & Metall., N.Y.*, 1929, **10**, 558; *Ceramic Abstr.*, 1930, **9**, 117. Improvements in ball mills, particularly with larger diameter mills. The drift away from rod mills to longer ball mills for fine grinding. The rod mill is still doing good work as a coarse grinder. There is also a modern tendency towards finer crushing, where crushers tend to encroach on the function of grinders.

1013. **Conical Ball Mill.** HARDINGE CO. INC., New York. Bulletins A.H–389–41, and 17–B–41. Full details of wet and dry grinding applications.

1014. **Fine Grinding Machines.** KLAR, H. *Ber. dtsch. keram. Ges.*, 1929, **10**, 285–313. Includes a description of the Hildebrandt ball mill for very fine grinding and a historical review of ball mill development.

1015. **Horizontal Axis Ball Mill with Peripheral Screening and Lifting Bays.** MARTEN, J. B. *U.S. Pat.* 2560972, 1947. The bays, arranged circumferentially, allow additional balls to be added and these cascade at a period later than normal. Comminution of small quantities takes place within the bays as they move round partially filled with balls.

1016. **Improvements Relating to Lining Plates for Drum Mills.** MIAG MUHLENBAU G.m.b.H. *Brit. Pat.* 722191, 1951/55. Silicon–chrome–manganese steel has proved very efficient for the lining of drum-type mills where shock resistance is important. A 'T' slot on the inner face for fixing bolts avoids fixing holes on the grinding face.

1017. **Ball- and Pebble-mills.** MILLER, J. O. *Amer. Ink Mkr.*, 1949, **27** (1), 23–6, 55–7. Ball mills ranging from small jars to full-sized mills, capacity 50–4000 gal, are described. The operation of such mills is mentioned briefly and a table is given for the charge, speed, etc., for mills of various sizes.

1018. **Ball and Tube Mills.** MITCHELL ENGINEERING CO., LTD., and MACPHEE, A. *Brit. Pat.* 594855, 1945/47. A modified feeding arrangement which obviates the hollow trunnion and archimedean screw and avoids accumulation of material at the entrance of the mill. A spider feeding mechanism is described.

1019. **The Preventative Maintenance of Ball Mills.** NICOL, A. *Enamelist*, 1950, **27** (2/3), 28. A somewhat detailed discussion covers most aspects of the subject. The most common contributing factors to mechanical depreciation are: misalignment, either when installed or subsequently due to bearing wear; incorrect lubrication; excessive tension in belt- or chain-driven machines; and overloading. 3 figs.

1020. **Pebble and Ball Mill Grinding.** A review. OLSON, V. R. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1944 (237), 340–4. Discusses pebble mills, plain and jacketed, and the higher grinding efficiency and lower costs of steel ball mills. 8 refs. to previous papers in the 'Official Digest'.

1021. **Crushing and Grinding Plant for Operation in the Mining Industry.** *Min. J.*, 25 Feb. 1955, **244** (6236), 208–11. The Marcy ball and rod mills in sizes up to 7 × 15 ft, made by Pegsons, are described.

1022. **Design, Construction, and Costs of Arc-Welded Pebble Mills.** PELLETT, D. L. *Paper Tr. J.*, 1932, **95**, T.A.P.P.I. Section, 289–92. Large-scale mills of this type have been made to withstand severe load conditions with a wide safety margin. The cost of arc-welding is substantially lower than that of other manufacturing methods.

1023. **Improvements Relating to Jacketed Revolving Apparatus.** PINCHIN JOHNSON, LTD. *Brit. Pat.* 717092, 1952/54. This concerns the means of connecting the cooling water supply to the jacket inlet: *see also* Pat. 687906.

1024. **How to Operate a Grinding Circuit.** RAMSEY, R. H. *Engng Min. J.*, April 1945, **146**, 96–9. An article based on practical suggestions of skilled men, designed to help beginners. A ball mill and wet classifier is described and a tabular guide is given showing symptoms of and remedies for faults in handling.

1025. **Special Types of Crusher.** RIEDIG, F. *Str.- u. Tiefb.*, 1949, 3 (11), 367–8. A description is given of the design and operation of a crusher which incorporates a ball mill. By varying the size of the balls it is possible to crush the material to any size required. Stationary and portable crushers of this type are discussed and illustrated.

1026. **Gear Failures of Ball, Tube and Rod Mills.** ROSE, H. E. *Engineer, Lond.*, 5 April, 1957, **203** (5280), 522–4. The breakdown of the gearing is discussed and it is suggested that failures are due to fatigue arising from surging of the charge in the mill, even though the latter is not manifest by noise or by circuit breaking to protect the motor. A criterion for surging is given and it is suggested that if mills were operated within the limits set down, the frequency of failures would be reduced and designs might be improved.

1027. **Sealing Device for Ball and Rod Mills.** ROUBAL, A. J., ALLIS CHALMERS, LTD. *U.S. Pat.* 2706656, 1955. Resilient annular rings, or rings in obturator form, are applied between the nuts and the outer shell or casing.

1028. **Ball Mill and Vapour Condenser.** SHAFER, L. M. *U.S. Pat.* 2511742, 1950. Equipment is described for maintaining the interior of a ball mill under reduced pressure and for condensing any vapour that is extracted. A bellows on the same shaft as the mill allows the movement of a reciprocating rod passing through it to clear any condensed liquid in the hollow trunnion, while vacuum is maintained, through a vacuum pipe at the outer end of the bellows.

1029. **Heavy Ball Mill Driving Problems.** SHERER, W. *Zement-Kalk-Gips.*, 1954, 7 (9), 349–56. Theoretical considerations are put forward on the selection of the most suitable driving motor, and test data are presented in support. Step-ring motors are more easily adapted to requirements than squirrel cage motors. An auxiliary motor is used as a brake instead of a mechanical brake, and a brake system in case of voltage failure is described.

1030. **Ball Mills, Rotary Kilns, and Like Rotary Apparatus.** SMIDTH, F. L., AND CO.

Brit. Pat. 597756, 1948. Costly end trunnions are eliminated and alternative supports are proposed.

1031. **Balanced Ball Mill System with Rotary and Vibratory Movements of the Ball Mill Units.** SMITH, E. W., VIBRO DYNAMIC ENGINEERING INC. *U.S. Pat.* 2693320, 1954. A pair of ball mill jars are mounted to rotate and also to vibrate.

1032. **Mill Feeding with Weight Feeders.** TAUBMANN, H. *Zement-Kalk-Gips.*, 1953, **6** (12), 445–9. An automatic feeding device for the tube mill makes allowances for variations in hardness of the clinker feed.

1033. **Ball Mills.** TORRANCE AND SONS, LTD., FRANKLIN, E. S. *Brit. Pat.* 648165, 1950. The use of cones instead of ribs for stiffening the end plates of water-jacketed ball mills is described.

1034. **Multiple use of Pebble and Ball Mills.** UNDERWOOD, E. M. *Industr. Engng Chem.* (*Industr.*), 1938, **30**, 905–8. An illustrated description of ball and pebble mill developments. Types of action, special processes and materials of construction are dealt with.

1035. **Ball, Rod and Tube Mills.** WARDELL, J. W. *Mine & Quarry Engng*, 1940, **5**, 255, 313. Notes on wet-grinding ball mills, rod mills, and tube mills are given, their points of resemblance and difference are pointed out, and their application in ore-dressing practice and the factors controlling their operation are discussed.

1036. **Rotatable Drum Mill with Annular End Wall Members Each Having Frusto-conical Deflecting Surfaces Thereon.** WESTON, D. *U.S. Pat.* 2704638, 1955.

CONCENTRA MILL

1037. **A Study of the Particle Size Distribution in a Concentra type Mill.** TANAKA, T. and SAITO, N. *J. Jap. ceram. Ass.*, 1952, **60**, 99. From a study of grinding rates of cement clinker in relation to its passage through a 5-compartment Concentra type mill, the most effective conditions of operation are deduced. *See under* Cement for longer abstract. *See also* Batel, W., previous section; *and under* Mittag, C., Crushing and Grinding Practice, General Papers.

BALL MILL, ROTARY, WITH VIBRATION

1038. **New High Speed Ball Mill.** CUMSTON, E. H. *Chem. Engng*, 1953, **60** (7), 338; *U.S. Pat.*, 2633303. This mill will operate at 100–140% of critical speed by means of an interruptor mechanism consisting of weighted arms (4) mounted on pinions, which revolve at higher speeds than the rotated drum and swing the weighted arms. The pinions are rotated by a large stationary gear mounted concentrically with the drum.

1039. **Vibratory and Rotary Ball Mill.** ROBINSON, R. S., VIBRO DYNAMIC ENGINEERING CORPN., Mass. *U.S. Pat.* 2613036, 1952. The principal object is to raise the critical speed, by means of a novel mechanical movement. The bearing supports are supported on helical springs, and a horizontal helical spring produces also a transverse vibration. The objects of a vibratory mill are attained and a higher critical speed is achieved.

1040. **Comminuting Machine.** TRIGGS, W. W., VIBRO DYNAMIC ENGINEERING CORPN., Mass. *Brit. Pat.* 689453, 1949. The output of ball and roller mills of material of a desired size can be increased if the balls and material are prevented from rotating with the housing at higher speeds. This is done by vibrating the housing at a predetermined speed independently of the rotation of the mill. The installation is described.

BALL, PEBBLE AND TUBE MILLS: THEORETICAL PAPERS

1041. **Genesis of the Hardinge Mill.** ANON. *Crush. & Grind.*, July–Aug. 1931, **1**, 47. A brief statement of early development of the conical mill in 1906. Two cones of

different angle were inserted in a cylindrical mill. It was found that the large pieces remained until broken down, the sizes both of ore and of pebbles arranging themselves in order of diameter. In 1908 comparative tests grinding copper ore in a tube mill, a Chile mill and a conical mill, showed the advantage to lie with the conical mill. The conical mill was thereupon adopted, 64 conical mills in one plant. The next advance was the substitution of pebbles by metallic balls, particularly for reducing ore from larger than ½-in. size. As the ball mill became established, so followed the gradual elimination of the stamp mill. Then followed the closed circuiting of mills and classifiers. In 1912 the manufacture of Hardinge conical mills began in England and came under the charge of J. C. Farrant, the constructor of the original conical mill.

1042. **The Mining and Dressing of Low Grade Ores in Europe. O.E.E.C. Technical Assistance Mission,** No. 127, 1953. O.E.E.C., Paris. Obtainable from H.M. Stationery Office. The G.E.C.'s Research Laboratories at Wembley work with an 8-in. diam. ball mill and Armstrong considers that the 12-in. mill as used in U.S.A. (12 in., 16 in. and 24 in. are used) is on the large size. Close correlation in results has been found between these mills and practice, but G.E.C. has not yet shown that a mill as small as 8 in. can give results comparable with large-scale practice.

1043. **Exploitation of Low Grade Ores in U.S.A.** *O.E.E.C. Technical Assistance Mission*, No. 228, 1954; Chap. IV. O.E.E.C., Paris. Obtainable from H.M. Stationery Office. Where 3-in. balls have to be used to break the largest sizes in one-stage grinding, these are found to be less effective than 1- or 2-in. balls for grinding smaller particles. One-stage grinding generally requires more power than two-stage grinding.

The spiral lifter, developed by Allis Chalmers, enables the material to advance more rapidly through the mill than does the usual type of horizontal lifter. Where balls are of different sizes, the latter type induces the large balls to segregate at the discharge end, whereas the spiral lifters cause migration of the large balls to the feed end.

1044. **Open Circuit Crushing in the Stillfontein Reduction works.** ANON. *S. Afr. Min. (Engng) J.*, 1952, **63**, II (3122), 629–31. A general account of the reduction works with flow sheet. The special feature is a vibratory grizzly, the first installed in South Africa, for classifying the −6-in. stock pile ore. Rod mills open circuit, then tube (pebble mills) are used. Space is saved by having the feed and flow at right angles to the length of the rod mills.

1045. **Some Experiments on Colloidal Grinding with a Ball Mill.** ANDREASEN, A. H. M., BERG, S. and KJAER, E. *Kolloidzschr.*, 1938, **82**, 37–42. A 5-litre porcelain drum was used for the experiments at the critical speed of 99 rev/min corresponding to $n=k/D$, with $k=42{\cdot}3$ and in which n=rev/min and D=the diameter. A large number of small steel balls (7·94 and 3·93 mm diameter) occupied 37·3% of the volume of the drum. The materials were finely ground heavy spar and polishing red, chosen because the iron impurities introduced during the grinding could be removed, without serious attack on the particles. The method of carrying out the analysis is described. Polishing red was more difficult to grind than heavy spar. Further, the smaller balls were more effective than the larger, but to a much less degree with polishing red than with heavy spar. The difference in the finest grain sizes was up to 50% with heavy spar and less than 10% with polishing red. Into the latter, 4% of iron was introduced during the grinding, but only 1% into the spar. After 24 hours' grinding 20% of the spar was below the 0·1 size, after 72 hours 48%; in the polishing red this fraction made up 15%. With the usual porcelain balls practically none of this fraction is obtained.

1046. **Optimum Conditions for Operating Ball Mills.** APPELL, F. (Mdme.) *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1950 (303), 315–22; *Brit. Lino. Res. Council Abstr.*, 1950 (11), 342. This is a bibliographical study of ball mills. Optimum conditions and the factors affecting the operating efficiency are dealt with.

1047. **Ball and Pebble Mills.** R. G. BAINES. Lecture; condensed in *Chem. Age.*,

Lond., 1945, 53 (1374), 390. A threefold action occurs in the dispersion of a fine powder in a liquid, viz., (a) the cascading of outer balls, (b) the rolling together of inner balls, and (c) the rubbing action between the balls and the inner surface of the mill. These are the cause of the simplicity of ball and pebble mills when in use, the low power consumption, and the consistent results. The author discussed the materials available for construction and points to be considered for facilitating cleaning and quick change-over. Steel ball mills were compared with porcelain pebble mills, and the advantage to be gained by incorporating lifter bars to overcome the slip inevitable with steel balls was explained. The use of compressed air and its limitations for discharging were mentioned. The difficulties to be borne in mind when transferring from laboratory to works practice were enumerated and a formula was shown for determining the critical speed, the usual speed adopted being 60–70% of this critical figure. Optimum figures for charge and pebbles were suggested and, in regard to dry grinding, the relation existing between diameter and time and output.

1048. **Relation of Milling Practice to Enamel Workability.** BAKER, R. J. and SHELDON, R. S. *Proc. Porcell. Enamel Inst. Forum*, 1953, **15**, 66–79; *J. Amer. chem. Soc.*, Oct. 1954, 175. An investigation was made with alumina balls to find methods of reducing milled enamel temperatures and frit solubility difficulties. The greatest single factor was the reduction of grinding speed from 18 to 13·75 rev/min (8 × 6-ft mill). Ball sizes greater than 2 in. are too large. Volume of balls was established at 45% of mill volume, and increase raises the temperature. Increasing the frit above 6000 lb decreases temperature but increases mill time.

1049. **Developments in Ball Mill Grinding.** BARKER, L. M. and LEWIS, E. G. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1361, 12 pp.; *Min. Tech.*, 1941, **5**; *Ceramic Abstr.*, 1942, **21**, 175. An attempt was made to test the statement that in ball mill grinding the best efficiency is obtained when the screen analysis of the sands shows a minimum crowding at any one size. A modified two-stage grinding circuit was in use. This showed crowding with most of the material in the −28 to +65-mesh screen sizes for both mills. The size of the ball make-up was reduced from 3 to 2½ in. for the primary mill and from 2½ to 2 in. for the secondary mill. There was less crowding in both, but less tonnage was ground. All new feed was then run through one mill on open circuit and then to three secondaries. This gave little crowding in the primary mill and a decrease in the secondary mill, but the classifiers gave trouble. When the ball make-up was changed to 50% each of two sizes, there was little change. Single-stage grinding was tried, but it was not more effective until ball make-up was changed to 30% 3 in. and 70% 2 in. This was adopted as grinding practice, although optimum conditions were not obtained.

1050. **Tube Mills in the Cement Industry.** BIRTHELMER, L. *Silikat Technik*, 1954, **5**, 163. The operation of tube mills for cement, the feeding of grinding media and their wear, are described in detail.

1051. **Calculating the Horse Power Consumed in (Cement) Ball Mills.** BLANC, M. E. C. *Rev. Matér. Constr.*, 1924, **174**, 57–60. *See under* Cement.

1052. **Some Remarks Concerning Close Packing of Equal Spheres.** BOERDIJK, A. H. *Philips Res. Rep.*, Aug. 1952, 7 (4), 303–13. Three criteria are stated for estimating the mean density of local configurations. Some configurations are described which may have a local mean density exceeding that of 'close packing'. It is proved that the maximum number of spheres simultaneously touching a sphere is 12. 6 refs. *See also under* Wise, M. E.

1053. **Determination of the Circulating Load in a Wet Closed Circuit Grinding System.** BOND, F. C. *Min. & Metall., N.Y.*, Nov. 1937; *Rock Prod.*, Jan. 1938, **41**, 64. The calculation is not based on screen analysis but on feed tonnage measurements, dilution and the amount of new material added. Formulae are given for wet and dry grinding.

1054. **Crushing and Grinding Calculations.** Bond, F. C. *Canad. Min. metall. Bull.*, July 1954, **47** (507), 466–72; *Trans. Canad. Min. Inst.* (*Inst. Min. Metall.*), 1954, **57**, 286–92. The theoretical relationship between work input and particle size is discussed. The mill volume, charge and nature of grinding media relations are discussed. 9 refs.

1055. **Increasing the Efficiency of Cement Ball Mills.** Capek, Z. *Stavivo.*, 1950, **28**, 286; 1951, **29**, 695. The development of ball mills was empirical and so is most of the research to make milling economical. The author's work embraces the results of 135 full-scale plant expts. and a series of laboratory scale experiments over the last 5 years. The measurements of the mill are: Exterior length = 13 000 mm, exterior diameter = 2200 mm; Chamber I: l=3040 mm, d=2040; Chamber II: =2440 mm, d=2040 mm; Chamber III: =6860 mm, d=2080 mm. It is sometimes believed that the output of the mill can be increased by introducing finely pre-crushed material into the mill, but this is untrue. A series of experiments was performed to find the degree of filling required to obtain a certain grain size after the minimum time. The results were used on large scale experiments varying the filling of each chamber to a limited extent. The decrease of the residue on 70 mesh in each chamber was plotted in Mittags diagrams. The correct course of the curve is the smoothest. Comparing outputs shows that the correct curve does not imply maximum output. The effects of changing the filling by 1% only at equal total load are very great. In one series of experiments chambers I and II were combined and filled with pre-crushed fine material, in another series chamber III was lined to increase the surface. The output of the mill was compared with the max. output of the mill in its original form. In both series of experiments the output was low. A diagram of the particle size curves, with Grafs curve for comparison, is given and the sizes giving max. output are shown. The belief that fresh clinker is more difficult to grind than aged clinker is shown to be wrong, and diagrams are given. The importance of the correct velocity is noted. Addition of electrolytes to the clinker and the use of non-magnetic balls was tried out successfully, increasing the output considerably, theoretical reasons are given. It is thought that the passage of ionized air through the mill might give results similar to the addition of electrolytes. 7 figs., 3 tables. [P]

1056. **Grinding Ball Classification. Its Effect on Ball Migration.** Carman, C. McA. *Rock Prod.*, June 1953, **56** (6), 106–9, 151. The effect of the Carman patent—ball classifying shell liners—is discussed and illustrated. These 'plates' are in the form of a series of short truncated cone having a slight slope, say 3°, sufficient to maintain classification of balls along the tube mill continuously, reverse ball migration being completely eliminated, as well as partitions of course.

1057. **Gold Metallurgy in the Witwatersrand.** Carson, D. L. 1949, Transvaal Chamber of Mines, Johannesburg. Chap. III. Pt. 4. A note on ball rationing. The relation between the product and size distribution of the ball charge is discussed, and performance figures are tabulated to serve as a guide to choice of ball size distribution. [P]

1058. **The Operation of Ball Mills.** Channell, D. R. *Industr. Chem. Mfr.*, 1951, **27** (313), 69–73. A discussion of the factors (eight are listed) affecting the operation of ball mills. Working data are assembled in tables and graphs in order to enable suitable working conditions to be ascertained. The headings are: total charge; volume of balls; size of balls; speed of mill; viscosity of wet batch; order of grinding; duration of grinding; initial grain size. [P]

1059. **Gold Mining in the Witwatersrand.** Clemes, A. and Moir, A. T. 1949, Transvaal Chamber of Mines, Johannesburg. Chap. III, pt. 2, pp. 92–125. Grinding crusher product in cylindrical mills to produce a one product, all slime pulp. The successful elimination of the intermediate stamp mill process by the introduction of ball mills for primary grinding is described (steel balls). A very full description of equipment and process (including classification) is given, together with tables of performance data and costs. [P]

1060. **Fine Grinding.** COGHILL, W. H. *J. Amer. Zinc Inst.*, 1929, **12** (5 and 6), 100. Account of early history and development of the ball mill, principally regarding the mechanics of milling. A new formula is given for ball paths.

1061. **Statistics on Early and Recent Ball Mills and Concentrators in the United States.** COGHILL, W. H. (Colorado School of Mines). *Mines Mag.*, July 1934, 5. [P]

1062. **Advantage of Ball (Rod) Mills of Larger Diameters and Advantage of Improved Bearings.** COGHILL, W. H., DE VANEY, F. D. and O'MEARA, R. G. *Trans. Amer. Inst. min. (metall.) Engrs*, 1935, **112**, 79–87. It is claimed that if a large mill and a small mill are run while centrally loaded and packed to working weights, weight times rev/min divided by net power should be the same for each mill. If this is not so, the one giving the small quotient has poor bearings. Tables of data. Discussion. [P]

1063. **Observations from Grinding and Crushing Tests.** COGHILL, W. H. and DE VANEY, F. D. (Colorado School of Mines.) *Mines Mag.*, June 1937, 7–10. (1) Relations between the amount of feed and circulating load and particle size of composite mill feeds, are investigated in detail. (2) Constant ratio is found between the amount of finished material and the arithmetical mean of surface of composite feed and circulating load. (3) The effect on mill capacity with finished material in the circulating load is to make the product finer and reduce capacity.

1064. **Conclusions from Experiments on Grinding.** COGHILL, W. H. and DE VANEY, F. D. *Bull. Mo. Sch. Min.*, 1938, **13** (1), 100 pp. The paper includes: an early history of size reduction and its modern history; three industrial epochs of the ball mill, study of variables and power losses in trunnions (the ball mill has few competitors); doubts about the application of the Rittinger law; a series of cardinal points in grinding, relating largely to the ball mill. 69 refs.

1065. **Power Consumption in a Small Ball Mill.** CONNOR, J. M. University of London, 1936, Ph.D. Thesis. Experiments were made in a ball mill, 20 in. diameter by 24 in. long, fitted with a glass front and driven through a transmission dynamometer. The casing was smooth. Balls were from ½ in. to 2 in. in diameter. Data were obtained with and without charge of material. Power measurements showed that when the ball charge was less than 40% of the mill volume, the torque remained constant with increasing speed. When the ball charge was more than 40%, the torque had a maximum value at 80% critical speed, and increased rapidly at higher speeds. The addition of dust to the ball charge reduced slipping and increased the power. Photographs were taken of ball paths and a critical examination was made of ball path equations.

1066. **The Ratio of Water to Solids in Cylinder Grinding.** CREYKE, W. E. C. and WEBB, H. W. *Trans. Brit. Ceram. Soc.*, 1941, **40**, 55. There is a sharply defined critical ratio of solid charge to water in cylinder grinding at which the grinding efficiency is a maximum. An important factor in securing grinding efficiency is the viscosity of the slip. The rate of production of fine material is higher at lower viscosities. It is possible to obtain greater grinding capacity, while maintaining the optimum viscosity for maximum efficiency, by the addition of a suitable deflocculant. When grinding mixtures of materials which grind at different rates a loss of efficiency may be caused through the early development of fines from the softer material which slow up the grinding of the harder material. The use of different forms of classifier have been developed to obviate this. In any case it would seem an advantage to add the softer material at a later stage of the grinding. Similarly, the inclusion of clays in a grinding charge, by increasing the viscosity, lowers the grinding efficiency. When grinding borax frits, stone and felspar, which develop alkalinity, it is usually possible to use a higher solid:water ratio than when grinding a material such as flint or quartz, because of the deflocculating action of the alkalis. The ratio of solids:water should be varied for each material being ground to obtain maximum efficiency.

1067. **Screened Ore for Fine Grinding at Lake Shore Mines, Ontario.** CROCKER, B. S.,

Lake Shore Mines. *Min. Engng, N.Y.*, 1952, **4**, 499–508; *Trans. Amer. Inst. min. (metall.) Engrs*, **193**. Increased steel cost and shortage of ½-in. balls led to development of pebble milling to grind from −8 mesh to 24% +28 microns. Tabulated results show: (1) shape of grinding media is unimportant below 8 mesh; (2) surface hardness has no effect; (3) capacity of media is directly proportional to its sp. gr.; (4) high discharge pebble mills are erratic; (5) low discharge mills use 40% more power and give 40% more capacity than high discharge pebble mills; (6) h.p. per ton milled is the same for pebble as for steel; (7) liners with some lift are required; (8) a slight decrease of solids of pulp over steel balls is recommended; (9) saving on steel consumption gives an impressive decrease in grinding costs. A practical method of converting steel to pebble mills to retain the same grinding capacity is outlined. Methods of obtaining, weighing and charging the pebbles is described in detail.

1068. **Ball Mills.** DALLAVALLE, J. M. *Micromeritics*, 1948, 2nd Edn. Pitmans, New York. Critical speed $Wc/s = 54{\cdot}2/\sqrt{}$radius of mill in feet. It is independent of the density of the material. Centrifugal force = centripetal forces, i.e. just short of falling off. Optimum ball size $D^2 = kd$, k depending on the material; 55 for chert, 35 for dolomite. A mill is most efficient at producing new surface when the ratio, initial diameter of particles to (ball diameter)^2, is approximately 600×10^{-8} (diameter in microns).

1069. **Ball Mill Crushing in Closed Circuit with Screens.** DAVIS, E. E. *Bull. Univ. Minn.*, 1925, (10), 25 pp. Calculates work done in open and closed circuits both by Rittinger law (surface units) and by Kick law (energy units). Efficiency increased with increased circulating loads.

1070. **Fine Crushing in Ball Mills.** DAVIS, E. W. *Trans. Amer. Inst. min. (metall.) Engrs*, 1920, **61**, 250–94; Discussion, 294–6. The large formation of hard siliceous rock at the Eastern end of the Mesabi Range contained fine grains of magnetite to the extent of 35%. To obtain the magnetite, it was necessary to crush to −200 mesh, after reducing the feed with aid of magnetic separation to a ¼ in. and discarding the rock containing little or no magnetite at each successive stage of crushing. A comprehensive investigation of the fine crushing was undertaken using a Hardinge conical mill 8 ft × 22 in., into the effects of all factors likely to affect efficiency and output. The ball paths and other aspects were investigated mathematically and the results compared with experimental data. Results are summarized in 16 conclusions. A mathematical analysis of ball wear is made, conclusions are itemized, and the data tabulated. Illustrations of ball paths. Discussion, 294–6. [P]

1071. **Pulp Densities within Operating Ball Mills.** DAVIS, E. W. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **167**, 155–9; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1843; *Min. Tech.*, 1945, **9** (3). Laboratory experiments on ball mill grinding of magnetic ores show that variation of composition of the pulp inside the mill was dependent on mill speed, and that it could differ considerably from the feed and output. High-speed cinematographs were taken to show ball paths and degrees of agitation.

1072. **Application of Ball Mills in South-East Missouri.** DELANO, L. A. and RABLING, H. *Trans. Amer. Inst. min. (metall.) Engrs*, 1921, **66**, 99–116. States that crushing tests with Hardinge and Allis-Chalmers ball granulators, using Gates crushing diagrams, show that ball mills operated to give low slime will show poor efficiency (thin pulps gave better results); capacity and nature of product are governed by mill speed, weight of ball charge, nature and size of balls, moisture in feed, and rate of feed; and highest capacity and lowest percentage of slime are obtained with large proportion of largest balls.

1073. **Fine Grinding and Classification.** DORR, J. V. N. and ANABLE, A. *Trans. Amer. Inst. min. (metall.) Engrs*, 1934, **112**, 161–77. Modern flotation and cyanidation of slime has made fine closed circuit grinding essential. The relation of classifier to the mill in this 'unit' process, and the effects of variables on particle size are discussed. Eight basic rules are stated.

1074. **Calculations of Energy Consumption of Tube Mills.** DREYER, H. *Zement*, 1929, 1434–9. The movement of charge in a ball mill is analysed and the effects of variables on output are determined. [P]

1075. **Collisions through Liquid Films.** EIRICH, F. R. and TABOR, D. *Proc. Camb. phil. Soc.*, Oct. 1948, 44, 566–80. A simple mathematical analysis is made of the hydrodynamic behaviour of a liquid layer interposed between two colliding surfaces.

1076. **A Commercial Application of Closed Circuit Grinding of Wet Process Cement Raw Materials.** ERNEST, E. S. Portland Cement Association Spring Meeting, 12 May 1931.

1077. **Grinding Investigations at Malmberget.** FAGERBERG, B. International Ore Dressing Congress, Goslar, May 1955; Gesellschaft Deutsche Metallhütten und Bergleute e.v. Clausthal. In the production of high-grade magnetite concentrate, since the latter has to be pelletized it must be ground to a specific surface of 1800 sq. m/g. Investigations have been carried out since 1950 to provide reliable grinding data. Results are: (1) The production of new surface increases with the fineness of the material. (2) A relatively high water-content is favourable for control of oversizes in rod milling. In ball milling of fine feed a thick pulp promotes surface formation. (3) Low-level ball mills produce more new surface in fine grinding than do overflow mills. (4) Greatest economy is effected in ball milling with a charge volume of 40–45%. Maximum capacity is obtained at 43–50%. The lower values are more suitable at high speeds. (5) Within limits, increased specific surface of the grinding media results in higher capacity and less energy consumption per ton through-put. This applies to ball and rod mills. (6) The capacity of fine grinding ball mills increases with the speed up to about 100% of the critical value, but this increase probably occurs at the cost of grinding economy at speeds higher than 70% critical value. In rod milling the capacity is proportional to the speed below about 100% critical value. (7) The design of mill lining has a decisive effect on new surface production. Smooth shell liners are recommended for high-speed mills. (8) The production of new surface in ball milling is proportional to the mill length and to the mill diameter to the power 2.5. (9) The production of new surface is not noticeably influenced by closing a ball mill circuit with a classifier. (10) As energy consumption, wear per ton through-put in fine ball milling seem to be at a minimum at lower speeds, higher pulp levels and lower charge volumes than would be recommended for obtaining maximum capacity, consideration should be given to optimal working when planning new mills.

The feed is −15-mm magnetite ore to be ground in three stages, rod mills in the first stage, and ball mills for the other two, all in open circuit. [P]

1078. **Particle Size Distribution of Products Ground in the Tube Mill.** FAGERHOLT, G. 1945, G.E.C., Gads Forlag, Copenhagen.

1079. **Grinding and Classification, I. Batch Grinding.** FAHRENWALD, A. W. *Rep. Invest. U.S. Bur. Min.*, No. 2989, Feb. 1930. The relationship was investigated semi-quantitatively between capacity of the ball mill and the fineness of the finished product. Power and wear were not measured. Size analysis at 3-min intervals up to 24 min was approximately linear (log log), but the influence of the feed was visible. Then decreases up to about 12 min, so that the plot became curved. The surface of the unfinished product v. time gave a series of parabolas with maximum value reached sooner for coarse than finer mesh. The feasibility of being able to measure the surface is questioned. Batch grinding with a simple grind could not be operated under any conditions to produce high efficiency. The percentage of finished product is a vital factor in ball mill efficiency. [P]

1080. **Grinding and Classification. II. Batch Closed Circuit Grinding.** FAHRENWALD, A. W. *Rep. Invest. U.S. Bur. Min.*, No. 2990, Feb., 1930. Mill efficiency is considered to be defined by conditions giving the maximum rate of output. These conditions are

investigated. The ratio, recirculated quantity to output, is a function of the fineness of the finished product for maximum efficiency. This ratio can vary from 10 to 2. [P]

1081. **Ball Mill Studies.** FAHRENWALD, A. W. and LEE, H. E. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 375, 1931. A theoretical analysis of ball mill action is given, and various equations for ball paths are developed. Variables are related by curves on the basis of data from small ball mills. It was found that the optimum speed of a mill 12 in. diameter by 4 in. long was 1·33 times the critical speed, but this is not in accord with results of other workers. [P]

1082. **Older Ore Dressing Practices Re-studied.** FAHRENWALD, A. W. *Engng Min. J.*, 1939, **140**, 73.

1083. **Why a Smaller Ball Load Gives a Better Milling Economy.** FAHRENWALD, A. W. *Engng Min. J.*, 1954, **155** (12), 79. Experimental grinds were run with ball loads at 45% and 29% of mill volume. The smaller load gave less ball consumption, less power consumption, and less overgrinding. These results were attributed to higher capacity for ore in the mill and higher ore to ball ratio. [P]

1084. **Ball Mills. Relative Noise.** (Data supplied to Dr. Heywood by Mr. Farrant of International Combustion, Ltd.)

Rel. noise .	76	80	80	70	70	83	60	78
Dry tons/24 h .	1270	1324	1250	1193	1170	1178	1104	1304
kWh/ton .	4·71	4·51	4·75	5·08	5·12	4·91	5·43	4·69
h.p. .	334	334	333	339	335	330	335	342

There appears to be an optimum value of relative noise (78) for the maximum output. [P]

1085. **A Review of Certain Unit Processes in the Reduction of Materials.** FARRANT, J. C. *Trans. Instn chem. Engrs, Lond.*, 1940, **18**, 56. In ball mill grinding, a coarse and/or a hard material entails a higher speed than a fine and/or a soft material. The critical speed, i.e. that at which the balls remain at the periphery, is given by $N=54{\cdot}18\sqrt{S}$ where S is the radius of the mill in feet less the radius of the balls. The use of 'lifters' in a ball mill is not generally economical owing to their rapid wear. A general value for the weight of mixed sizes of balls taken from a working mill is 300 lb/cu. ft. For a given reduction the following general rules may be applied: (1) a small diameter mill requires larger balls than one of large diameter; (2) hard and tough materials require larger balls than friable minerals; (3) high-density slips require an average larger size than a thinner slip; (4) a wide range of reduction of a hard mineral requires a similar range in ball sizes; (5) large-diameter balls minimize fines in the product; (6) small balls, by reason of their greater surface, produce maximum fines.

1086. **Study of Milling and its Effects on Properties of Porcelain Enamel Slips.** FELLOWS, R. L. and MCLAUGHLIN, J. L. *J. Amer. ceramic Soc.*, 1939, **22**, 260. Variations in the amount of frit charge, amount of ball charge, size of balls, and rev/min of the mill were found to change the fineness distribution of a white steel enamel. Other variables, such as the water content, temperature of milling, and pressure under which the enamel was ground, had apparently little effect on the fineness of the enamel. An increase in grinding temperature decreased the $Na_2O:B_2O_3$ ratio of the mill liquor and decreased the set of the enamel. Variation in milling under the conditions stated had no effect on the opacity or gloss and texture of the enamels.

1087. **Dispersion of Pigments by Ball and Pebble Mills.** FISCHER, E. K. *Industr. Engng Chem.* (*Industr.*), 1941, **33** (6), 1465–71. Optimum conditions for the operation of steel ball mills for pigment dispersion have been investigated in mills ranging from laboratory to production sizes. Microscopic examination was used as the criteria for evaluation. Dispersion rates were correlated with ball size, relative volumes of ball and charge and mill diameter. By adjustment of the formulation to allow proper cascading of the balls, and by maintaining the charge only slightly in excess of voids, the milling times can be shortened. In this way laboratory mills can provide a close

indication of the results obtainable with production size mills. 16 refs. *See also under* Superfine Grinding. [P]

1088. **Pigment Dispersion with Ball and Pebble Mills.** FISCHER, E. K., ROLLE, C. J. and RYLAN, L. W. *Off. Dig. Fed. Paint Varn. Prod.*, 1948 (287), 1050–64. Construction and operating factors are considered. Mill speed should be 50–65% of critical and ball load should be 40–55% of total mill volume. A slight excess of charge over ball voids is most rapidly dispersed. Viscosity should be the highest consistent with free cascading.

1089. **The Working Mechanism in Ball Mills, Especially in Tube Mills.** FISCHER (HERMANN). *Z. Ver. dtsch. Ing.*, 1904, **48**, 437–41. Gives results of investigations of ball movements by observations through screen ended mills. By observing dry balls only, he concludes (1) that no grinding is done by attrition, only by impact; (2) at slow speeds, the balls roll down the inclined heap, but at higher speeds they are thrown in an arc to the bottom; (3) the falling balls do not come down in clusters, but in series, the balls of each row keeping to their own line of flight according to their distances from the wall while ascending; (4) at critical speed the balls adhere to the wall; (5) the line of flight may be computed for each ball. They influence each other's flight at the apex of the course; (6) the speed recommended is correct, 76–83% critical.

1090. **A Supplementary Theory of Fine Grinding.** FRY, A. T. *Chem. Engng Min. Rev.*, 5 Aug. 1923. Shows that higher efficiency is to be expected by extra contact area; crushing in a ball mill is dependent on the area of contact which depends on size of ball and angle of nip; and the smaller the ball the smaller the area. The same idea may be applied in rolling action, where the area of contact is a ribbon instead of a circle as in impact crushing. Comparison of tonnage through two pebble mills gave 5% more finer material for the smaller pebbles.

1091. **How to Obtain Efficient Ball Mill Operation.** GARLICK, O. H. and ABBE, P. O. *Brick Clay Rec.*, Sept. 1952, **121** (3), 56–7. A practical study of a laboratory jar mill in order to determine the operating conditions necessary to obtain efficiency. For dry grinding of ceramics in mills not greater than 36 in. diameter, it was considered that best results were obtained with mill speeds from 55 to 60% of the critical velocity. The solids in the mill should be between 25% and 33% of the total mill volume and the balls should occupy about 50%. In wet-mill grinding there was an optimum consistency of slurry in which the balls or pebbles moved freely but without the tendency to float or sink. *See also Proc. Porcel. Enam. Inst.*, 12th Forum, 1950, 27; *Ceramic Ind.*, 1950, **55** (5), 59.

1092. **Grinding Plant Research.** GILBERT, W. *Rock Prod.*

Part I, General Principles and Fundamentals of Tube Mill Grinding, 21 Nov. 1931, **34**, 39. Enumerates the factors involved in ball mill investigations. Curves are shown relating the ratios a/d and Rg/d with volume of ball charge, d being the diameter of the mill, a the depth of the upper surface of the ball charge below the centre of the mill when at rest, and Rg the depth of the centre of gravity of the ball charge below the mill centre under the same conditions. Bulk density of steel balls found to be 282 lb/cu. ft, corresponding to a void content space of 42·5%. Cylpebs had a voidage of 43% and flint stones of 42%. An expression is derived for the path of a single ball, ignoring the effect of slip. Horsepower factors also determined by theory.

Part II, Tests of Cement Clinker Grinding Mills, 27 Feb. 1932, **35**, 27. Describes tests on the above mills. The preliminary grinding mill was 71 in. diameter, fitted with 6 lifter bars $\frac{9}{16} \times 1\frac{1}{2}$ in., and balls up to 4 in. diameter. The finishing mill was 71 in. diameter with smooth casing and used flint stones for grinding. Graphs show the sieving analyses of the product along the length of the mill.

Part III, Method of Obtaining Reference Curve and Additional Clinker Grinding Tests, 26 Mar. 1932, **35**, 22. The reference curve is defined as the percentage residue on 180-mesh sieve plotted against the relative energy per unit weight of product. Straight line relationship exists up to about 40% residue, i.e. 60% passing the sieve;

curves become flattened at 95% passing the sieve. The b.h.p. hour per ton varied from 20 to 48 for a fineness of 15% residue on 180 mesh when grinding coals in a Kominor mill.

Part IV, Tests of Coal Grinding Mills, 23 April 1932, **35**, 40. Gives detailed description of tests on Kominor and tube mills. New surface in sq. ft per b.h.p. hour was 137·2 for Kominor mill and 114·8 for tube mill. [P]

Part V, Tests of Coal Grinding Mills (continued), 4 June 1932, **35**, 24. Further experiments described. [P]

Part VI, Grinding Tests on Coal and Clinker in Tube Mills and on Standard Sand in Experimental Mill, 2 July 1932, **35**, 35. Experiments were made with tube mill 52 in. diameter by 25 ft long, using 3¼ tons of flint balls: firstly with continuous feed and secondly with closed outlets. The reference curves for the two cases were very similar, the residue being very slightly greater with continuous feed. Subsequently an 18 × 18-in. mill was constructed. Two types of lining were used in this mill, namely, smooth and with 8-in. square section lifters respectively. The experiments on the 18-in. mill with lifters are described in this section. [P]

Part VII, Tests on Standard Sand in Experimental Mill, 27 Aug. 1932, **35**, 23. Notes on the ratio of material to void space in ball charge. Optimum conditions found to be obtained when this ratio was 80% with 1-in. balls, and 60% with cylpebs, this being based on the charge volume at the beginning of the test. The increase in the volume of the material after grinding was 35–45%. Most suitable speed factor, i.e. the constant in the equation $N = c/1\sqrt{d}$, was found to be about 180.

Part VIII, Tests on Standard Sand in Experimental Mill with Smooth Lining Plates, 8 Oct. 1932, **35**, 23. The above tests were repeated with smooth casing. The smooth casing was found to be slightly more efficient than the lifters, but the speed of rotation should be slightly higher.

Part IX, New Surface Produced by Grinding, June 1934, **37**, 31. Sizing analyses made by repeated sedimentation in distilled water at time intervals of 6 hours, 1 hour, 10 minutes and 100 seconds; depth of sedimentation 7½ cm, 6–10 sedimentations were usually required, and the fractions were then measured microscopically. The surface area assuming spherical particles was 610 sq. ft/lb for a fineness of 6·76% residue on 180 mesh. A statistical method of particle measurement was applied to a hypothetical rectangular prism having proportions of 10 × 6 × 4 units, and the ratio of geometrical to spherical surface found to be 1·48. Curves for particles of different proportions are shown, and the value of the above ratio may be taken as 1·5–2.

1093. **Laboratory Investigations of Ball Milling.** Gow, A. M., Campbell, A. B. and Coghill, W. H. *Trans. Amer. Inst. min. (metall.) Engrs*, 1930, **87**, 51; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 326; *Ceramic Abstr.*, 1930, **9**, 336. (1) Observations have been made with a 3-ft squirrel-cage mill. A new theory of ball action has been advanced from this study, and a new formula of ball paths has been derived. (2) Laboratory tests with short ball mills in which slippage was reduced to a minimum have shown that the best grinding results were obtained at lower speeds than those hypothecated by previous theories. A speed of 65% of the critical gave the maximum grinding, while a speed of only 50% of the critical gave the most efficient grinding. (3) By comparing the grinding results of the mills of various diameters, it was found that at the same percentage of the critical speed: (a) the units of surface per unit weight varied as the 0·6 power of the diameter; (b) the surface tons, or grinding capacity, varied as the 2·6 power of the diameter; (c) the horsepower also varied as the 2·6 power of the diameter; (d) the surface ton/h.p.-h, or efficiency of grinding, was constant regardless of the diameter; and (e) the units of surface per unit weight varied approximately as the peripheral speed. (4) The larger mills showed larger grinding capacity per unit volume, but no increase in grinding efficiency. H.p. $= [(L/2-1)K+1] \times (D^{2\cdot 6}/2)$, where $K = 0{\cdot}9$ for $L =$ less than 5 ft, and 0·85 for $L =$ greater than 5 ft.

1094. **A Laboratory Investigation of Milling Methods.** Gow, A. M., Campbell, A. B.

and COGHILL, W. H. *Trans. Amer. Inst. min. (metall.) Engrs*, 1930, p. 51. The phenomena of *cascading* and *cataracting* of balls is investigated at ball loads from 10 to 50%. It is concluded that the fallacy of the old parabolic theory lies in the fact that the balls do not act independently when they leave the shell, but continue in contact, pushing those ahead until they pass the apex of their flight. The continuous upward stream of balls cannot lose velocity, and consequently there is a horizontal velocity at the apex of their flight equal to the peripheral velocity of their circular course. Segregation: at critical speed large balls tend to go to the centre. At slower speeds, the large balls tend to go to the outside. Dead load was determined for each mill by rotating a concentric weight equal to charge at the various speeds. Net power is presumed to give the energy expended within the shell. Graphs.

1095. **Dead Load Ball Mill Power Consumption.** GOW, A. M., GUGGENHEIM, M. *Engng Min. J.*, 1932, **133**, 632. The dead load of a ball mill is defined as the external friction loss. To determine this a 6-ft diameter by 4-ft long mill was shortened by a bulkhead and the shortened section completely filled with balls whose weight equalled the normal load when grinding. At a speed 80% of critical the dead h.p. was 11. The normal input when grinding is 87 h.p., with a motor efficiency of 90%; thus the dead load power is 13% of the electrical input.

1096. **Ball Milling.** GOW, A. M., GUGGENHEIM, M., CAMPBELL, A. B. and COGHILL, W. H. *Trans. Amer. Inst. min. (metall.) Engrs*, 1934, **112**, 24; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 517. Discusses horsepower, capacity and efficiency with variations in speed, ball sizes, pulp density and feed rate. [P]

1097. **Treatment Plant Operations at Giant Yellowknife. (Gold mine.)** GROGAN, K. C. *Canad. Min. metall. Bull.*, April 1953, **46** (492), 212. Performance data are presented for the ball mill operations. [P]

1098. **A Device for Determining Work Input to a Laboratory Ball Mill.** GROSS, J. and ZIMMERLEY, S. R. *Rep. Invest. U.S. Bur. Min.*, No. 3056, 1931, 3 pp. This paper describes a simple type of torsion dynamometer for measuring the power input to a small ball mill. The torque is measured by the extension of three springs placed between two discs, one being on the mill shaft and the other on the driving shaft. The speed factor is measured by means of a differential integrating meter. The two meters are combined to give a direct reading of the power to the mill. Details of the design are given.

1099. **Grinding Experiments on an Open Circuit Tube Mill.** GROSSE, H., FORDERREUTHE, and RAMMLER, E. *Ber. Reichskohlenrates*, No. 25; *Zement*, 1930, **19**, 189. Mathematical expressions are derived for relationships between power and fineness of output.

1100. **The Effect of Mill Speed on Grinding Costs.** HARDINGE, H. and FERGUSON, R. C. *Min. Engng, N.Y.*, 1950, **187** (11), 1127–30; 1951, **188** (12), 1222. Laboratory and plant data covering twelve different operations show that ball mill speeds lower than 'standard' increase grinding efficiency. In the case of high pulp level mills, the gain is so great that the increase in capital cost of the larger lower speed mill will pay for itself in less than a year. Power and ball cost per ton of −200-mesh product decrease with decrease of speed. Low speed high-capacity mills should be installed for economy. 1 fig., 9 tables. Discussion by F. C. Bond, pp. 1149–50. [P]

1101. **Ball Paths in Tube Mills.** HAULTAIN, H. E. T. and DYER, F. C. *Trans. Canad. Inst. Min. Metall.*, 1922, **25**, 276–92; *Bull. Canad. Inst. Min.*, 1922 (122), 651; *Trans. Amer. Inst. min. (metall.) Engrs*, 1923, **69**, 198–207. Quotes E. W. Davis' outstanding paper—Fine crushing in ball mills, *Trans. Amer. Inst. min. (metall.) Engrs*, 1920, **61**. The present paper is copiously illustrated with photographs showing the paths of balls in ball mills, taken at 120 exposures per second, using a glass-fronted ball mill so that ball paths and slip could be studied.

1102. **On Cylinder Grinding.** HELM, G. *Ber. dtsch. keram. Ges.*, 1932, **13**, 196. Data obtained from a questionnaire issued by the German Ceramic Society to about sixty firms are critically examined. The average number of rev/min for cylinders of 1400 mm and 1700 mm diameter, viz. 23 and 19 respectively, in wet grinding, agrees closely with the theoretical number as calculated by Mellor, *Trans. Engl. ceram. Soc.*, 1910, 9, 50. The theoretical basis of wet and dry grinding is discussed at some length. After a detailed discussion of all the factors which influence the grinding efficiency, it is concluded that further work is necessary on the following five factors, both in wet and dry grinding: number of rev/min; the ratio of material: grinding medium; water; optimum amount of charge; size of grinding media, especially flints; and effect of lining material. [P]

1103. **Power Requirements Greatly Reduced in a New Compound Tubular Mill.** HERMANN, R. *Concrete, N.Y.* (Cement Mill, Section 42), Nov. 1934, **42**, 35. The tube is divided into five longitudinal cells. The optimum charge of grinding media, 20–40% of volume of mill depends on their shape and on the shape of lining plates. This percentage determines the speed of the mill and power requirements. The distance of the media from the centre of the mill creates a reverse moment of rotation. It is shown how the power requirements of the mill may be calculated from the mill data.

1104. **Tests with Different Sizes of Ball Mills.** HEYWOOD, H. *Combustion Appliance Makers' Association*, Document No. 1650, Rev. No. 18/03/31, 18 Feb. 1938. Tests showed in grinding with different coals that perfect dynamic similarity for the mills of various sizes was not obtained, but that it is possible to bring different size mills to a common basis of co-ordination. Graphical presentation of results. [P]

1105. **Fine Grinding Machines.** HINCHLEY, J. W. *Crush. & Grind.*, 1931, **1**, 39–40. Size reduction may take place by three distinct methods: crushing; shearing or grinding; impact. Grinding machines may be classified according to which of these methods predominates. The various types of machines are discussed from this point of view. The author regards crushing as superior to shearing or impact and mentions the ball mill as being the machine where all these occur. For wet grinding, he recommends rev/min to be $200/d^{-2}(d=\text{feet})$ or $200/(12d)^{-2}(d=\text{in.})=87{\cdot}4\times d^{-2}$ and higher speeds for dry grinding. He considers ovoid shape of ball media to be better than spherical media.

1106. **Tumbling Mill Capacity and Power Consumption as Related to Mill Speed.** HUKKI, R. T. *Min. Engng, N.Y.*, 1954, **6** (7), 728–30. Theory indicates that the general equation relating mill capacity and speed $=T(\text{capacity})=CN^m$ ton/h, where m is between 1 and 1·5, and C is a factor related to the grinding characteristics of the ore, method of reduction, and units chosen. Data indicate that the expression is reasonable. 7 refs.

1107. **Model Experiments with a Ball Mill.** I. G. FARBENINDUSTRIE. Obtainable in microfilm or photostat form from: Lending Library Unit, D.S.I.R. Reel No. M-91, FDX 523, p. 2, Frames 1664–90, 1947. Observations from operations of a glass-sided ball mill are mathematically interpreted and design data are deduced.

1108. **Experiments on the Konzentra Fitment for Ball Mills.** I. G. FARBENINDUSTRIE. Obtainable in microfilm or photostat form from: Lending Library Unit, D.S.I.R. Reel No. M-91, FDX 523, p. 2, Frames 1711–36, 1947. The fitment introduced by Krupp Gruson consists of an arrangement of baffles as illustrated. Experiments on batches of dyestuffs are described.

1109. **The Efficiency of Tube Mills.** JACOB, K. *Silikat-technik*, 1953, **4**, 73–4. A 'composite efficiency' number is suggested as a measure of the efficiency of any type of tube-mill grinding any type of material. This number is obtained from a formula derived from the following individual calculations: (1) power consumption (kWh) on the main shaft, (2) output (ton/h), (3) specific output (kg/kW/h), (4) output per cu. m

of grinding space, and (5) residue of ground material on a B.S. 170 sieve, and a factor relating to the type of mill and product as shown in the table provided.

1110. **Dependence of Grinding Capacity on the Degree of Filling of Tube Mills.** JACOB, K. *Silikat-technik*, 1955, **6** (6), 260–1. Tests and theory show that the optimum ball filling is 0·28. Curves for practical use are given. [P]

1111. **Grinding.** JOISEL, A. *Bull. Soc. Franc. Céramique*, 1950, 420; 1951, 15. Summarizing his studies on the theory of grinding, the author explains the principles of the operation of ball mills, tube mills and Alsing cylinders. The balls should not occupy more than 45% of the volume of the cylinder, and the latter should not rotate too rapidly, otherwise the balls and charge are merely centrifuged with no grinding action; neither should the speed be too slow, in which case the path of the balls is too close to the cylinder wall to be effective. Moreover, if the speed of rotation is rather low, the larger balls tend towards the centre and the smaller ones towards the walls, whereas the reverse is true if the speed is rather high. It was also found that the specific surface, which characterizes the fineness of the product, is exactly proportional to the duration of grinding for a period of about $1\frac{1}{2}$ hours, after which it remains constant. The max. fineness obtained depends therefore not on the grinding time but on other factors such as the humidity of the material and the size of the balls. The surface of the grinding bodies should be between $\frac{1}{100}$th and $\frac{1}{500}$th of that of the material to be ground. A brief example indicates the calculations for the weight and diameter of the grinding balls. 10 figs. *Trans Brit. Ceram. Soc.*, 1951, **50** (2), 61, Abstract Section.

1112. **Internal Mechanism of the Ball Mill.** JOISEL, A. and BIREBENT, A. *Rev. Matér. Constr.*, 1951 (434), 311–20; (435), 347–55; 1952 (436), 7–12; (437), 46–52; (438), 70–4; (439), 93–101. After a historical review, consideration is given to theories of ball trajectories, grinding power, the charge and its movements. The second part comprises an experimental study which confirms the theory developed in the earlier parts with regard to speed of rotation and degree of filling. *See also Publ. tech. Cent. Industr. Liants hydraul.*, No. 51, 1952. Mechanics of Ball Milling; abstract in *Ann. Min., Paris*, 1953, **142** (11), 15.

1113. **Modern Ball- and Pebble-Mill Technique.** KENDALL, S. W. *J. Oil Col. Chem. Ass.*, 1932, **15**, 66–96. The following types of ball mills are in use: (1) those with stone linings and balls, of which Belgian silex and Danish pebbles are the most satisfactory; (2) those with porcelain balls and linings; (3) cast-Fe or steel mills with cast Mn–Cr–Fe alloy or forged-steel balls (Brinell hardness should be not greater than 500). Tightly coiled, hardened steel spirals are efficient grind media. Mills over 3 ft in diameter should be geared. Water-jacketed mills should be used for material sensitive to the slightest heating effect. Cylinders with the internal surface corrugated give increased efficiency. Eccentric ball mills give more rapid grinding, but with increased power consumption. A modern development is the use of lifting bars parallel to the axis of the mill and spaced 12–24 in. apart and $\frac{1}{8}$–$\frac{1}{4}$ diameter from the internal surface of the cylinder. Rubber linings (usually 1 in. thick) when not affected chemically or dissolved by the material being ground, last six times as long as 4-in. silex linings. Rexman balanced rod mills give increased grinding and reduced power consumption. The smaller are the balls, subject to the limitation that they do not float in the mixture being ground, the better is the grinding. For mills of the same diameter steel balls are more effective than pebbles. The working speed (formula given) should be such that the balls are carried to the highest point of the mill, from which they cascade rapidly. The best grinding speed is that requiring the max. power. The balls should occupy 45% of the volume of the mill and the voids between the balls (=18% of the volume) should be filled with the material (e.g. paint) being ground. In practice the material occupies 55–60% of the volume to save handling charges. The working life of a lining is 10 000 hours; the wear on the balls varies from 1–3% for cast alloy to 20–30% for porcelain balls per 1000 hours. 10 refs.

1114. **Ball Wear in Cylindrical Mills.** KETELBEY, H. F. W. *J.Chem. Soc. S. Afr.*, 1943, **44**, 20–4. Batch-grinding in a small laboratory mill suggests that grinding with large and small balls is most efficient when the total surface areas of the two types of ball are equal. Relative wear varies as surface area only when equal volumes of the two types are present.

1115. **Gold Mining in the Witwatersrand.** KING, A. 1949, Transvaal Chamber of Mines, Johannesburg. Chap. III, pt. 1, pp. 69–91. Tube milling, following fine crushing in stamp mills. General description of process and equipment, with illustrations, drawings of parts, and tables of performance results. Particular attention is paid to liners. [P]

1116. **Pebble or Ball Mills for Grinding.** KLEINFELDT, H. F. *Chem. metall. Engng*, 1923, **29**, 436. Discussion of factors affecting fine grinding and of the desirability of combining grinding and mixing in a single operation. An example in the paint industry.

1117. **Grinding Circuits Applicable to Cement and Aggregate Industries.** KLOVERS, E. J. *Rock Prod.*, 1952, **55** (2), 123–32. The author examines different circuits for wet and dry grinding, single-stage and multi-stage, open and closed circuits. The principles are pointed out with the help of diagrammatic sketches.

1118. **Study of the Grinding Process in Small Ball Mills.** KRUG, H. and SCHWANDT, K. *Keram. Rdsch.*, 1932, **40**, 93, 126. The effect of varying certain conditions on the fine grinding operation in small ball mills was studied. Experiments were carried out with specially hard porcelain ball mills, in which there was practically no wear on the walls. The material ground was porcelain glost pitchers. The results are tabulated. The grinding effect increased with increasing quantity of balls and also on increasing the size of the balls. The effect of the quantity of water is of comparatively less importance. The quantity of material being ground affects the grinding period directly; there must be sufficient empty space in the mill to permit efficient grinding. In practice, the same quantity of material to be ground will always be fed to the mill. The grinding effect increases with increasing number of revolutions up to the point where the centrifugal force is too great to allow the balls to fall from the walls of the cylinder.

1119. **Fine Grinding Investigations at Lake Shore Mines.** LAKE SHORE MINES STAFF. *Trans. Canad. Min. Inst. (Inst. Min. Metall.)*, 1940, **43**, 299–434. A report on seven years experimenting on grinding Lake Shore ores, with major emphasis on tube milling. The investigation is essentially a fact-finding one. No theories are developed. The object of the work was to increase the capacity of the plant and if possible to reduce costs of unit grinding at the same time. A thorough investigation was made on screens, infrasizers and their correlation. The Haultain infrasizer was in effect an air elutriation process done in a series of tubes whose diameters increase by the square root of two, making the critical air velocity decrease successively by half. The standardizing that results is presented graphically, as well as the results of test runs. The types of failure in infrasizing were thoroughly investigated, the effect of variables analysed and the possibility of use for separation of ultra fine sizes was investigated. Tabular comparison of data obtained by Lake Shore Mines with that of other firms is given. The second section of the report pp. 352–395 devoted to presentation and discussion of data obtained over the period 1933–35 on fine grinding in ball and tube mills with varying conditions of operation with a substantial subsection on ball wear. Smaller sections deal with laboratory investigations, pp. 401–13, and with classification reports. A discussion on the defects of screens and the calibration of 325-mesh cloth is presented on pp. 306–11. No specific relationship between the sieving value of the screen and the various dimensional features is evident although there is an apparent tendency for the sieving value to follow the average aperture size, it is apparently impossible to define the sieving value of a screen from dimensions alone. Calibrations from practical tests, which can be related to the results from an arbitrarily chosen master sieve, are recommended. The calibrations will not of course be the same for different materials.

The standard screen analysis procedure is described. This report is one of the most comprehensive reports to be found and contains many illustrations, curves, tables, etc., with a few references included in the test. A previous report is referred to in *Trans. Canad. Min. Inst.* (*Inst. Min. Metall.*), 1936, **39**, 279–434, by the Lake Shore Mines Staff. [P]

1120. **Ball Mill with Biconical or Cylindrical Drums.** LEBEDEV, A. N. *Bull. All-Un. Heat Engng Inst.* (*Izv. Vsesoyuz. Teplotekh. Inst.*), 1947, **15** (6), 15–21; *Chem. Abstr.*, 1950, **44** (13), 5652h. From extensive experimental data on the pulverization of coal, it is concluded that the biconical has no advantage over the cylindrical drum mill.

1121. **The Remarkable Case of the Copper Hill Ball Mill. (Hardinge Tricone Mill.)** LEWIS, F. M. *Engng Min. J.*, 1953, **154** (6), 86–9; (9), 80–3. Improved performance with copper ores has been attained by reducing the ball load. Results were a 5% increase in tonnage, 25% reduction in horsepower, less wear and 16% reduction in flotation agent. The overlying pool with less ball charge permits sinking of the heavier sulphides for further grinding, and discharge of the lighter gangue. 35 tons of one-inch balls were used instead of the full charge of 55 tons. Appreciations are given by H. R. Banks, H. E. T. Haultain, D. H. Fairchild, Lendrum and Parc, A. O. Gates, L. E. Djingheusian. The latter connects the ball load with the operating speed. Illustrations.

1122. **Ball-, Tube-, and Pebble-mills.** LOMAS, J. *Int. chem. Engng*, 1949, **30**, 461–4. The construction, operation, and applications of the various types of mill, including rod- and combination-mills, are described. The replacement of the spur gear drive of tube- or combination-mills by a central drive results in a power saving at the switch-board of 9·4 kW per 100 kW consumed by the mill. The advantages of compound mills of large capacity are discussed and operating characteristics are given for a mill 45 ft long by 8 ft 6 in. diameter. The stored energy at full speed of the empty mill is about ¼ that of the mill loaded with the mixed grinding media (75 tons). At full speed (20·5 rev/min) the angle of the cascading mass (75 tons of media + 11 tons grit) is about 50° to the horizontal; about 5 full turns are made before this position is reached, a normal mill requiring a starting-up torque not greater than 110–115% of the full load torque when a starting-up period of not less than 30 seconds is used. *Also Int. Industry*, 1949, **30** (10), 461–4. The power absorbed by a machine-cut gearing is 12% of the total driving power when new, and 15% when worn.

1123. **Low Pulp Level Ball Mill.** LONGMORE, E. L., *et al. Canad. Min. metall. Bull.*, 1937, 85; *Bull. Instn Min. Metall., Lond.*, Feb. 1937.

1124. **The Ball Mill.** MCLAREN, D. C. *Canad. Min. J.*, 1944, **65**, 21–7. A discussion of the practice of ball mill grinding. A comprehensive review of the developments within the last ten years is discussed. 30 refs. Some 15 variables in ball mill design and operation are discussed. A short discussion of rod mills follows.

1125. **Fundamentals of Grinding.** MCLAREN, D. C. *Canad. Min. J.*, 1943, **64**, 705–11; 1944, **65**, 153–9. General considerations of size reduction and a more detailed discussion of the individual factors in a ball or tube mill which affect size and output. In the second article the design features of tube mills are discussed. 30 refs.

1126. **Tube Mill Grinding, with Special Reference to Grinding in a Current of Air.** MARTIN, G. *Trans. Instn chem. Engrs, Lond.*, 1926, **4**, 42–55. The author found that grinding in a current of air did not appreciably save power. Compares measurement of quartz surface by the amount dissolved in 1 hour to that by amount dissolved from a quartz cuboid. Describes electrical method of measuring power used in ball mill crushing. Ball mill experiments showed that the surface produced is proportional to the work, but when grinding very fine the amount of surface produced falls off, which is ascribed to a cushioning of the charge. *See also* Martin *et al.*, *under* Fundamental Aspects, General Papers.

1127. **Studies in Cylinder Grinding,** MELLOR, J. W. *Trans. Engl. ceram. Soc.*, 1909–10,

9, 50–73. Following a theoretical consideration of the motion of pebbles in a ball mill, consideration is given to the best speeds for dry and wet grinding to obtain maximum efficiency. Slab mills, eccentric ball mills and conical mills are described.

1128. **A Review of Modern Ball Milling.** METCALFE, J. E. *Mine & Quarry Engng*, 1945, **10** (1), 3. A discussion is given on the work done on ball milling including the theory of ball milling, feeding and discharge and feeding and discharge equipment, fineness of grinding and the classifier.

1129. **Grinding Ceramic Materials in Ball, Pebble, Rod, and Tube Mills.** METZ, G. F. *Bull. Amer. ceramic Soc.*, 1937, **16**, 461. A study is presented of the so-called slow-speed types of apparatus, i.e. the conical and cylindrical ball and pebble mills, tube mills and rod mills, employing the impact or attrition method of grinding or a combination of both. The principles of open v. closed circuit grinding are discussed. A list of nine typical grinding problems is given with their solutions in detail. Finally, a number of general rules are cited which should be applied in the selection of any one of the mills discussed.

1130. **Recent Developments in Grinding Ceramic Materials in Pebble, Ball, and Tube Mills.** METZ, G. F. *Bull. Amer. ceramic Soc.*, 1945, **24**, 357. Grinding liners and balls, flint, Jasper adamant, zircon and porcelain, are compared for life and efficiency. The problems of grinding hard and fibrous materials are discussed. Mixing of fine powders and grinding to desired screen-size proportions of granular fines and moist materials are described. The importance of grinding in flotation separation is stressed, and the type of mill is given. Auxiliary equipment, such as control of feed by the Electric Ear, is considered in detail.

1131. **Determination of Ball Mill Size from Grindability Data.** MICHAELSON, S. D. *Ceramic Age*, 1945, **46**, 141; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1844. *See under* Grindability.

1132. **Pigment Dispersion by Ball and Pebble Mills.** MILLS, W. G. B. *Nat. Paint Bull.*, Dec. 1946, **10**, 5–6. A detailed account of the mechanism of operation of ball and pebble mills and the conditions requisite for maximum efficiency. Mellor's formula for mill speeds is quoted, and examples of efficient operation are given. Rev/min$=43{\cdot}3\sqrt{1/(D-d)}$.

1133. **Control of Grinding Mills.** MITCHELL ENGINEERING CO. *Australian Pat.*, 161028, 1952. The level of the material in a mill is controlled by introducing a stream of gas at a pressure higher than that in the mill. It is applied periodically to scavenge the system. The rate of supply of feed is adjusted to the air pressure.

1134. **Wet Grinding Enamel.** MOREN, G. *Verre et Silic. industr.*, 1947, **13**, 22. Mill speed is determined by two factors. The first function of linear speed is to cause the pebbles to roll on the walls and on themselves, and also to pull them towards the upper part of the mill in such a way that a pebble rides from the wall to the top of the pile, but instead of falling, rolls down over the upper surface of the inclined pebble bed. The latter is a function of centrifugal force, which must be able to keep a pebble at a height equal to 2/3 diameter. Various formulae have been offered by different authors. Stuckert (*Die Email Fabrikation*, 2te. aufl. 1941, p. 184) estimates that speed must vary from $n=28\sqrt{d}$ for large mills to $n=32\sqrt{d}$ for small mills. A graph relates speed, weight of pebbles and additions for a mill of one metre inside diameter.

1135. **Modern Tendencies, in American Ore Dressing Plants, in Crushing and Grinding.** MORTSELL, S. *Tekn. Tidskr., Stockh.*, 1949, **79**, 601–4. In American ore dressing plants the tendency to run ball and tube mills at lower speeds has continued and is considered to improve efficiency and reduce lining wear. Larger mills are, of course, necessary for equivalent output.

1136. **Improvements Relating to Charging Ball or Rod Mills with Fine Material and to Discharging Material.** MOTE, H. *Brit. Pat.* 686983–4, 1949/53. A method is claimed

for discharging a ball or rod mill by pneumatic means in the continuous grinding of finely divided material.

1137. **The Causes of Caking and Scale Formation in Tube Mills and the Remedy.** MUHLHÄUSER, R. *TonindustrZtg*, 1954, **78**, 371. Two methods are usually applied: (1) The addition of a harder material which remains granular and tends to part from the grinding media and remove adhering material. (2) The addition of carefully regulated quantities solids or liquids which tend to vaporize with the development of heat and so clear the grinding media. The author, however, uses the addition of a cleaning or polishing agent, which, in regulated quantity, enables the grinding media to rub themselves clean.

1138. **Some New Views and Methods of Interpretation.** MURKES, J. (Royal Institute of Technology, Stockholm.) *O.E.E.C. Technical Assistance Mission*, No. 127, 1953. 1954, O.E.E.C., Paris. Obtainable from H.M. Stationery Office. Outlines the work of the Research programme at the Royal Institute of Technology, Stockholm. He points out how a transfer from 60-mm balls to 30-mm balls saves about 20% of time in grinding to a specific size and how the classification quotient also is lowered (in grinding diabase). Even on long grinding the quotient is much less for small balls than for large ones. A smaller quotient is obtained with rods, on parallel lines to the smaller balls. He briefly reviews the work on Fahrenwald, Lee and others in the developing the idea of optimum ball size, and quotes Olevsky's formula and statement that an optimum ball size corresponds to the lowest grinding time required for a given degree of fineness. A series of curves illustrates the advantages of smaller balls. 4 graphs. For classification quotient. *See* No. 100, Kihlstedt.

1139. **Progress Report on Grinding at the Tennessee Copper Co.** MYERS, J. F. and LEWIS, F. M. *Min. Engng, N.Y.*, 1950, **2**, 707–11, 1133–66; *Trans. Amer. Inst. min. (metall.) Engrs*, **187**, 707–11. The first year of experimental operation of a large diameter slow-speed ball mill with 1-in. balls, including a hydro-oscillator, and with and without classifiers. Operating data with the Hardinge Tricone Mill. A slow-speed mill with small balls offers an interesting field of investigation. A 28% increase in efficiency was obtained.

The second report, 1133–66, presents comments regarding ball consumption and data pertaining to the oscillator which is closed circuited with the tricone mill. A study and postulate of how balls function is presented. Cascading and impacting of balls is unnecessary and inefficient for the fine ore particles from a fine crushing rod mill. Reconciling grinding efficiency with good metallurgy is still a problem. Diagrams of ball wear and particularly to polyhedrons. [P]

1140. **Contribution to the Theory of Tube Mills.** NASKE, C. *Zement*, 1929, **18** (11), 236; *Build. Sci. Abstr.*, 1929, **2**, 194. A critical examination of Fischer's theory of the tube mill according to which the comminution is effected by impact alone and not by grinding with or upon the heap of balls in the revolving mills. On the basis of the power consumption of a tube mill, it is concluded that the theory does not hold and that comminution is the result of both grinding and impact.

1141. **A New Theory for the Ball Mill and Some of its Applications.** NERONOV, N. P. *Bull. Acad. Sci., U.R.S.S.*, tech. sci. (*Izv. Akad. Nauk., U.S.S.R.*, O.T.N.), 1949 (7), 1067–83. A translation may be consulted at D.S.I.R. Ref., Records Section, 5122, 1951. A mathematical analysis of the motion of shell and charge of a ball mill. To the two recognized stages of the motion of the balls, the author adds a third, that is the stage from the instant of leaving the drum to the beginning of the parabolic motion. In pages 1082–3, L. B. Levenson comments on the paper, and the author replies on p. 184.

1142. **Contribution on the Use of Ball Mills.** OUTIN, J. *Peint-Pigm.-Vern.*, 1952, **28** (8), 544–8. An account of some conclusions reached, following the application to

ball mills of theories of the dynamics of fluids, and a simple method of calculating and determining *a priori* the theoretical composition of the paste to be fed to the mill.

1143. **Recent Basic Advances in Fine Grinding of Minerals in Wet Ball Mills. Application to Mineral Dressing.** QUITTKAT, G. *Z. Erzbergb. Metallhüttenw.*, 1949, **2** (1), 6–14. A discussion of movements of charge in the ball mill, the effects of variables and modifications in the design of mill and gratings. A short survey of theory precedes.

1144. **Fine Grinding in Tube Mills.** PEARSON, B. M. *Rock Prod.*, 1952, **55** (12), 106. The reduction of electrostatic charge is described. *See under* Dust Hazards.

1145. **The Coal Pulverizing Plant at the McGill Smelter of the Kennecott Copper Corpn.** PESOUT, E. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 197–202. Description of airswept ball mill equipment, and performance data. *See under* Coal. [P]

1146. **Controlled Milling of Ceramic Materials.** PODMORE, H. L. *Pott. Gaz.*, 1952, **77**, 1740. In the ball milling of ceramic materials, efficiency is raised by use of a deflocculant. Practical examples are given of operations of batch grinding from which it is possible to work out grinding efficiencies on the basis of grindability comparisons, physical characteristics and surface area requirements. An example is given of the calculation for power requirements for grinding borocalcite to a desired fineness, on the basis of its behaviour as compared with a known felspar determined experimentally. Relationships are presented graphically. Rittinger's law is assumed to be valid in this paper.

1147. **Tests on Tube Mill with Air Separator. Performance Data for the Process are Determined.** PROCKAT, F., RAMMLER, E. and MULLER, W. *TonindustrZtg*, 1934, **58** (11, 12, 13, 15). The test procedure described is a useful guide to the testing of similar mills pulverizing coal. Data on the following relations are presented graphically: air flow against throughput, throughput against fineness, total surface of product and residue on a No. 70 D.I.N. sieve, kW against airflow and kW against throughput. The total surface produced per hour is almost constant for all rates of pulverizing. Curves of kWh/ton against fineness and against throughput summarize the results of these tests. [P]

1148. **Sub-sieve Sizes in Mineral Dressing.** PRYOR, E. J. *Min. Mag., Lond.*, 1945, **72**, 329–37. The author discusses the formation of sub-sieve sizes (−200 mesh) in the ball mill and their examination, including the determination of sub-sieve surface area by means of turbidimeters and gas-adsorption methods.

1149. **Getting the Best Production from a Ball or Pebble Mill.** REDD, O. F. *Bull. Amer. ceramic Soc.*, 1940, **19**, 253. A discussion of each of the operating variables in ball and pebble mills and their inter-relation is presented. These variables are: mill speed; the amount of grinding media; the size of grinding media and of material charge; the amount and consistency of the material. A standard set of operating conditions is chosen and the effect of deviations from each variable is discussed.

1150. **A Physical and Chemical Basis for Mill Selection and Operation.** REDD, O. F. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1952 (324), 29–41. Discusses basic principles influencing selection of grinding equipment, especially ball and pebble mills.

1151. **Ball Mills.** REINHOLD, K. *TonindustrZtg*, 1916, **40**, 102. The advantages of ball mills for brick and tile makers are discussed. *See under* Ceramics.

1152. **Some Physico-Chemical Problems in Construction.** RIDEAL, E. K. *Chem. Ind., Lond.*, 1946, **65**, 210. Grinding in a ball mill may involve both direct impact and shear. If friction or attrition is playing a part a considerable percentage of fines is produced, whereas if there is impact a more granular product will result. The 'viscosity factor' will also be of importance in controlling the movement of the powder in the mill. Roughness also plays a part in determining the work of shearing a powder.

1153. **The Probability Theory of Wet Ball Milling and its Application.** ROBERTS,

E. J. *Min. Engng, N.Y.*, 1950, **2**, 1267–72; 1951, **3**, 1219; *Trans. Amer. Inst. min. (metall.) Engrs*, **187**, **190**. Reasons are given for discarding the two methods of evaluating grinding efficiency, (a) by new surface developed and (b) percentage passing a particular screen. Unless it is known how classification affects grinding, it cannot be hoped to improve classification effectively. A theory was developed based on the chances of a particle being crushed in a particular ball mill arrangement, and on the classification of the feed, it being proved during the tests that the rate of reduction through any mesh is roughly proportional to the percentage above that mesh. It is also shown that the rate of reduction is substantially proportional to the h.p./ton applied to the balls, and is independent of the size of the mill. A relative grindability procedure is outlined. 6 refs.

1154. **Calculations made on the Rotary Furnace and the Tube Mill.** ROCK, E. *TonindustrZtg*, 1942, **66**, 420–5. A mathematical analysis of the operation in the above mills based on dimensions of the plant.

1155. **Surging in Ball Mills.** ROSE, H. E. and BLUNT, G. D. Paper to the Institution of Mechanical Engineers, June 1956; Summary in *The Chartered Mechanical Engineer*, June 1956. The paper shows that for speeds of rotation greater than 0·15 critical speed, the existence of surging will depend on D/d and on Ju where D is the diameter of the mill and d the diameter of the charge, J is the fractional filling of the mill by the ball charge and u is the arithmetic mean of the coefficients of static and dynamic friction of the ball and powder charge. (1) For speeds less than 0·15 critical, surging is not likely to occur. (2) For greater speeds, the existence or otherwise of surging may be established by noting the zone on a graph of Ju plotted against D/d in which the point corresponding to the operating condition of the mill falls. The test results suggest that this criterion applies to both mills with unbroken cylindrical surfaces and to mills fitted with loading hatches. It is shown that nearly a hundred large industrial mills for which data are published are operated under conditions which accord with the criterion given and so, even though the criterion is to some extent empirical, it is adequate for design purposes. The experimental study was conducted with small scale models.

1156. **The Dynamics of the Ball Mill. Pt 1. Power Requirements Based on the Ball and Shell System. Pt 2. The Influence of the Powder Charge on Power Requirements.** ROSE, H. E. and EVANS, D. E. Institution of Mechanical Engineers, Paper, June 1956. In Pt 1 the relation between dynamic variables and power requirements to drive a ball mill, containing a ball charge but no powder charge, has been investigated by means of small scale models. The functional relations between dimensionless groups are given analytically or by means of graphs. Mills with lifters and without lifters are best treated as separate cases, but the variation in the number and size of lifters has little effect on power requirements. As a result of this work, the power input required to drive a mill grinding powder may be calculated with reasonable accuracy, and examples of these calculations to large mills are given. In Pt 2 the relation between the relevant dynamic variables and the power required to drive a ball mill containing both balls and charge is established. By means of the results in Pt 2, the power required to drive a mill in which a granular material is being dry ground may be calculated with an accuracy sufficient for design and operational purposes. The additional power required when the mill is grinding powder is in proportion to the excess weight as compared with the balls alone, provided that the powder does no more than fill the ball voids.

1157. **A Mathematical Analysis of the Internal Dynamics of the Ball Mill on the Basis of Probability Theory.** ROSE, H. E. Paper to the Institution of Chemical Engineers, London, 7 Nov. 1956. This is probably the first paper in which the subject has been studied from a purely theoretical standpoint of the probability of occurrence of the various processes taking place within the active zone around the contact points of balls. Expressions for the evaluation of the most important characteristics of the ball mill

have been deduced on the basis of a number of postulates clearly stated at the commencement of the analysis. The more important of the conclusions drawn have been verified by experiments upon a ball mill enclosed in a calorimeter. It is shown that Rittinger's law for a ball mill has no theoretical justification, any straight line being obtained being solely due to conditions of grinding, and that finer grinding can sometimes be obtained when the void space is not completely filled with powder. This increase is at the expense of increased ball wear, a feature which has been observed in practice. It is also shown on theoretical grounds, that the rate of grinding attains a maximum when a definite fraction of the void space is filled with powder. A series of 11 curves embody relations between the variables considered, i.e. probability of particle being crushed, relative hardness of ball and particle, specific surface and time of grinding, equilibrium number of particles and filling ratio, total wear, change of surface, specific surface and energy absorbed to the filling ratio.

In the discussion, the author refers to the paper by K. Engels in *Metall*, 1954, **8** (3/4), 102–7, 'The Mode of Action of Ball Mills in Fine Grinding', where for grinding hard materials the ball media should be made of tough but not hard material, so that penetration of the ball surface by the product grains reduces wear of the metal.

1158. **Progress in Ball Mill Design.** RUDORFF, D. W. *Engng Boil. Ho. Rev.*, 1940, **54**, 180; *Ceramic Abstr.*; 1940, **19**, 240. Grindability or relative resistance to pulverization and the influence of moisture content upon ball-mill output are discussed, particularly in relation to pulverized coal. Data on power consumption for certain types of ball mill are given, including data for the Russian ball mill (Fridkin drive). It is concluded that smaller balls reduce the amount of extremely fine material, 0–10 microns, and increase the 15–30 micron sizes. Operating and physical data are given and fluctuations in ball size during operation owing to wear are presented graphically. [P]

1159. **Slag Grinding Tube Mills.** SANDT, P. G. van. *Concr.-Cem. Age* (Cement Mill Section), 1913, **2** (3), 29–30. The low horsepower consumption, repair cost, and their reliability make them the most economical machine for Portland cement manufacture.

1160. **Approximation of Energy Efficiencies of Commercial Ball Mills by the Energy Balance Method.** SCHELLINGER, A. K. and LALKALKA, F. D. *Min. Engng, N.Y.*, 1951, **3**, 523–4. *Trans. Amer. Inst. min. (metall.) Engrs*, **190**. The controversial nature of energy efficiency figures led to an approximation of such efficiencies by an energy balance of kinetic, heat and surface energy for a mill grinding cement raw materials. All considerations gave the energy efficiency approximation formula:

$$\text{Percentage Energy Efficiency} = \left(1 - \frac{\text{Thermal Energy Output}}{\text{Kinetic Energy Input}}\right) \times 100$$

Results of calculations made by and with the methods and data discussed are tabulated. Thermodynamic efficiencies obtained by these approximations seem to confirm the results of other workers.

1161. **New Ball Mill.** SCHOTTEN, W. *Metall.*, 1950, **4**, 276–8. *Chem. Abstr.*, 1950, **44** (20), 9194g. To grind small quantities of hard material to a very fine powder, a steel tube, three-quarters loaded with steel balls is used. Mathematical theory of ball mill grinding is discussed. A fineness of 0·1–0·5 micron can be obtained in a few minutes.

1162. **Ball-mill Practice.** SECHRIST, H. *Proc. Porcel. Enam. Inst.*, Forum. Oct. 1939, 136–47; *Ceramic Abstr.*, 1940, **19**, 154. As ball size decreases, total milling time decreases. In a 3 × 4-ft. belt-driven mill, using one half 2-in. and one half $1\frac{1}{2}$-in. balls, there is a 25% saving in production time over any other combination, and no unground frit is left in the mill. The loss in weight of the balls is practically the same in every combination of ball sizes used. If the balls are all of the same size, the mill lining may become grooved and wear out rapidly. Ball charge should always be kept at 50–55% of the mill volume for most efficient grinding. New balls should be added when the old ones have become worn down to $\frac{3}{4}$ in. size. The water content must be controlled accurately, as too much and too little water both increase milling time. Frit charges

must be carefully checked; too large a charge requires much longer grinding, and too small a charge causes excessive wear on linings and balls. Milling at too high a speed can cause loss of set through heating up of the enamel. Tables and charts are presented.

1163. **Contribution to Ball Mill Theory.** SEDLATSCHEK, K. and BASS, L. *Powder Metall. Bull.*, 1953, **6** (5), 148–53. A suggested mathematical theory. *See* No. 397.

1164. **The Laws of Grinding in Cylindrical Mills.** SEGUITI, T. *Rev. Industr. min.*, July 1952, **33**, 537–46. The author reviews the principles of grinding and the graphic presentation of reduction from one size range to another, and also discusses the conclusions drawn from the prior experimental work. He then presents the results of a large number of industrial trials in cylindrical mills in tabular and graphic form, the latter being intended to enable the prediction of results of any proposed grinding operation in cylindrical mills. The results presented are for hard and soft minerals and for normal and slow-speed operation. [P]

1165. **Cylinder Grinding.** SHENTON, R. *Trans. Brit. Ceram. Soc.*, 1911, **10**, 14–32. A general description of operations (with costs) of ball mill grinding. Discussion.

1166. **Belgian Experiments in Clinker Grinding.** SLEGTEN, J. A. *Rock. Prod.*, Sept. 1946, **49**, 60–1. Translated from the French and abstracted by Dr F. O. Anderegg for *Rock. Prod.* The results of over 20 years' clinker grinding experiments carried out in the plant of the Société Cimenteries et Briquettes Réunies. The conclusions of Geoffrey Martin (*J. Soc. chem. Ind., Lond.*) in the early 1920s have apparently been confirmed. These concern optimum size of grinding media and its weight ratio to feed weight; the criterion of a residue on a 200-mesh screen gives no accurate idea of the work done; optimum grinding speed is calculated from the mill dimensions, best size and composition of balls. (1) 30–40% ball load is best, but requires proper selection of ball sizes and of charge weight. (2) The optimum speed is $58\sqrt{D}$ but the tendency is to work at 70% critical speed to conserve power. (3) Optimum charge is 30%.

1167. **Grinding in Ball Mills and Tube Mills.** STARKE, H. R. *Rock. Prod.*, June 1935, **38**, 40–6. Starke studied the following variables, using four grinding mills of varied sizes and types for grinding Portland cement clinker: (a) length of grinding period; (b) size of grinding balls; and (c) initial size of particles to be ground. Within the conditions of these tests on a commercial and semi-commercial basis, the following generalizations may be stated: (1) During early periods of grinding in batch mills the specific surface of the charge increases nearly in proportion to time, but during later periods the rate of increase tends to diminish. (2) Mill efficiency is influenced by variation in the rate at which material is fed to a continuous discharge mill. (3) A mill is most efficient in producing surface from the material used in these tests when the ratio $\left(\frac{\text{initial particle diameter}}{(\text{ball diameter})^2}\right)$ (in microns) is about 600×10^{-8}. (The optimum value of this ratio depends upon the physical characteristics of the material to be ground.) (4) Products of grinds at low ratios have appreciable weights of all particle sizes smaller than the charged size, while those of grinds at high ratios have a small weight of particles between $\frac{1}{16}$ and $\frac{1}{2}$ the charged size. (5) By scalping the product at commercially feasible particle sizes, high grinding ratios usually yield products of highest specific surface. (6) Materials of equal specific surface will generally have particle-size distributions more nearly alike when produced at equal grinding ratios. Thirty series of curves are presented. [P]

1168. **Problems of Fine Grinding.** STEINER, D. *TonindustrZtg*, 1936, **60**, 537. Effects of different grinding media on sand, clinker and limestone are investigated in a laboratory ball mill 22 in. in diameter by $11\frac{1}{2}$ in. long. The table gives the time in minutes required to grind to 20% residue on a 180-mesh sieve:

Grinding Media	Sand	Clinker	Limestone
Cylpebs 20 mm diameter .	67	53	90
„ 11 „ „ .	66	48	50
Spheres 30 mm diameter .	73	60	70 [P]

1169. **Fine Grinding in Ball Mills.** STEINER, D. *Chem. Age, Lond.*, 2 Oct. 1937, **37**, 274. The *Chem. Age* quotes the *Chemisches Laboratorium für Tonindustrie und Tonindustrie Zeitung, Berlin*, 1937, as describing the position of the different fine grinding processes on the continent of Europe.

1170. **Tests on the Hardinge Mill (Of Adjustable Length).** TAGGART, A. F. *Trans. Amer. Inst. min. (metall.) Engrs*, 1918, **58**, 126. An illustrated account of grinding tests. Among the conclusions are that the ball mill works more efficiently on material of intermediate size (0·5–0·75 in. average) than on either a coarser or a finer feed; that steel balls are much more efficient crushing media than pebbles; that increase in the weight of the ball load (other conditions remaining constant) increases the ratio of production and the relative mechanical efficiency of the mill; that the relative mechanical efficiency of the ball mill increases with the average size of ball in the crushing charge up to 5 in. average diameter, and also with the rate of feed to the point of overload; that the relative mechanical efficiency of the mill (other conditions being constant) is a maximum at between 40 and 50% moisture content in the feed; that the relative mechanical efficiency in wet crushing is decidedly greater than in dry crushing. Work accomplished was calculated on the basis of Kick's law. In discussion, Bell suggests that the conclusions might be different if calculated on the basis of Rittinger's law. The tests indicated that the effects of mill speed on other variables had apparently been overlooked hitherto. Equations and graphs give means of calculating horsepower requirements. [P]

1171. **A Study of Particle Size Distribution in a 'Concentra' type mill.** (In Japanese.) TANAKA, T. *J. Jap. ceram. Assoc.*, 1952, **60**, 99. For abstract, *see under* Cement.

1172. **Ball Mill Grinding Studies of Several Ceramic Materials. I and II.** (In Japanese.) TANAKA, T. and SAITO, N. *J. Jap. ceram. Assoc.*, 1952, **60**, 228–30, 362. The materials studied were limestone, ganister, coal, cement clinker. Curves are presented showing the relations for these materials between residue and grinding time, specific surface (permeability method) and grinding time, residue and specific surface on a 0·088 (?) sieve.

1173. **A Study of the Pulverization of Coal by Means of the Ball Mill.** WANG, J. S. Thesis for Ph.D., London University, 1939. A detailed account of results by use of dynamometer to measure torque is given.

1174. **Operation of Drum Type Material Reduction Mills Employing Ball Charges, and Material Reduction Mill Employing Ball Charges.** WESTON, D. *U.S. Pats* 2680568, 2680570, 1951/54; *Chem. Engng*, 1954 (9), 258. The mill is provided with highly upstanding, spaced crusher bars and the method provides for the use of large balls occupying no more than about 3% of the mill volume, while the total charge occupies from 20% to 32% of the mill volume. Results are tabulated in the specification, for friable and tough material and use of steel and tungsten carbide balls at 1% of mill or less volume, at 84–90% of critical speed. Comparisons of output with and without balls showed no increase for friable material but large increases when balls were used for tough material.

1175. **Investigation of Mechanical Action in Steel Ball Mills.** WHEELER, G. B. *Paint, Oil. chem. Rev.*, 1948, **11** (25), 12–4. Action in a Lucite mill with glycerol–water mixtures or a non-drying alkyd, is studied by a cinematograph record. For effective grinding the charge should be of viscosity 90–115 Krebs units. A charge of $\frac{1}{3}$–$\frac{1}{2}$ balls and $\frac{1}{3}$–$\frac{1}{2}$ liquid appears best. Optimum speed of rotation is just below critical speed.

1176. **The Theory of the Tube Mill.** WHITE, H. A. *J. metall. min. Soc. S. Afr.*, 1904–5, **5**, 290. An equation is developed for ball paths. From experiments made with a short mill with glass end plates, the actual critical speeds were found to be greater than the theoretical owing to slipping. The best speed is defined as that corresponding to maximum torque.

1177. **The Theory of Tube Milling.** WHITE, H. A. *J. chem. Soc. S. Afr.*, 1915, **15**, 176. Variables are classified into two groups, (1) concerning design, and (2) concerning mill operation. Experiments were carried out in a large experimental mill 6½ ft diameter by 1½ ft long. It was found that with about 50% filling, the maximum power was at 27 rev/min (86% critical). An oscillograph showed that violent current fluctuations occurred, being zero at some instants; also every fourth was different from the others. Fluctuations in speed were found to be only slight.

1178. **Cascading v. Cataracting in Ball Mills.** WHITE, H. A. *J. chem. Soc. S. Afr.*, 1930, **31**, 1. Cascading occurs at a speed of 10 to $15\sqrt{D}$ rev/min (5% critical), D being the diameter of the circle of reference in inches. With 50% ball loading the outer boundary of the ball paths is almost a straight line. At a speed of 150 to $200/\sqrt{D}$ rev/min (60–80% critical) the limit of the ball paths is a parabola reaching beyond the lower limit of the rebounding balls. This type of motion is termed cataracting. Data are given relating power and speed for various conditions of running. The effect of moisture is investigated. [P]

1179. **Grinding Tests on Conical Trunnion Overflow and Cylindrical Grate Ball Mills.** WHITE, J. *Min. Engng, N.Y.*, 1950, **2**, 96; 1951, **3**, 2004; *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, **187**, **190**. This paper gives details of the results of careful testing carried out on two types of ball mills—conical trunnion overflow and cylindrical grate discharge—on identical ore. The object of the test work was to determine which ball mill was the most economical to install for future extensions to the Mufulira concentrator. 3 tables. In this paper an interesting comparison is made between the energy used to disintegrate the material by various processes and that required to shatter by impact test. The relative efficiencies based on impact tests are as follows: Mine blasting, 0·7%; crushers, 4·4%; stamp mills, 10·5%; tube mills, 18·6%. (Cf. Bond, 1954, who found explosive and mechanical efficiencies to be equal.) [P]

1180. **Direct P. F. Firing of Shell Type Boilers.** WILSON, R. Pulverized Fuel Conference, Institute of Fuel, 1947, 543–51. While power consumption is higher for the ball mill than for the ring roll and high-speed impact pulverizers, it is generally conceded that for dependability, low maintenance costs and fineness of grinding, the ball mill more than holds its own. The simplicity of the ball mill is its virtue. Performance data in the firing of two boilers are tabulated. [P]

1181. **Recent Tests of Ball Mill Crushing.** WINKLE, C. T. Van. *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1918, 227–34, discussion, 235–48. Describes the introduction of tube mills for ores, to do in one pass what the stamps, rolls and Huntingdon mills could not do. Pebbles became the grinding medium in tubes 20 ft long. Ball mills were in use outside U.S.A., but were small and costly. The present paper reports the results of comparison between the new Hardinge ball mill and the Marcy ball mill. The latter was better on capacity and power consumption. *See also* Gottesberger, R. B., *ibid.*, Preprint, 1918.

1182. **Ball, Rod and Tube Mills.** WITHINGTON, W. H. *Industr. Engng Chem.* (*Industr.*), 1938, **30**, 897–904. A description of the design and mode of operation of all types of the above mills, with a chart of grinding data for a dozen materials for varying purposes. Closed circuit grinding and classifiers are described. [P]

1183. **Recent Developments in the Application of Dry Fine Grinding with Air Classification.** WRIGHT, H. G. *Rock Prod.*, July 1930, **33**, 57–9. Deals mainly with the operation of a conical ball mill with reversed current air classification. Air is blown in through a central pipe in the discharge trunnion, and on reversing in the mill itself, provides a preliminary classification.

1184. **Copperhill Ball Mill; a Mathematical Explanation.** ZANNARAS, J. P. *Engng Min. J.*, 1955, **156** (5), 100, 115. The author has deduced an equation which embodies the optimum conditions for the impact forces at the toe of the ball load. The variables

in the equation should be so adjusted that the impact stress of the cascading equals the crushing strength of the rock at the maximum size of feed. Outside the optimum the impact stress will either fail to break or cause waste of energy and slimes.

1185. **Criteria for Oscillations of the Media in Ball Mills.** ZEISEL, H. G. *Verein Deutsche Ingenieur.* Fachgruppe, Staub-technik. Conference on Dust Behaviour and Air Purification, Dec. 1955.

1186. **On Drum-Mills.** ZEYEN, G. *TonindustrZtg*, 1913, **37** (42), 558–9, 1085–8, 1612. Power consumption and performance data under various conditions of operation. (This theoretical article was greatly welcomed at the time.) The merits of tube mills v. high-speed mills are discussed and capacities per h.p.-hour of various mills grinding cement clinker and coals are tabulated. In the last article the author replies to criticisms by Stroeder and Beneke. [P]

OPEN V. CLOSED CIRCUIT GRINDING

1187. **Closed Circuit Grinding.** ANON. *Edg. Allen News*, 1956, **35** (404). The air classification and oversize return system are illustrated for use with ball mills and the 'Rema' Ring Mill.

1188. **From Open to Closed Circuit Grinding with Liquid Cyclones.** ANON. *Rock Prod.*, 1953, **56** (7), 62–6. *See under* Cement. [P]

1189. **Open or Closed Circuit Mills for the Grinding of Cement.** ANSELM, W. *TonindustrZtg*, 1950, **74**, 11–5. The compound open-circuit ground cements always proved superior, especially when very finely ground. It is also more economical. 2 figs., 1 table. *See under* Cement.

1190. **Air Separation Type Mill or Compartment Mill?** BORNER, H. *Zement-Kalk-Gips.*, 1952, **5** (8), 242–54. A critical investigation of these two types leads to the following conclusions. The greater difference in grinding characteristics between the harder, heavier and more valuable constituents and other constituents of the rock, the greater the economical superiority of the air separation mill. Present German practice shows that the additional air separation equipment cost is only justified if the fineness is to exceed 4000 Blaine (cf. *Ceramic Abstr.*, Aug. 1951, 143b). Curves of operating behaviour and grain distribution for German and American cements are included. 17 refs. [P]

1191. **Closed Circuit or Open Circuit Grinding.** BORNER, H. *Pit & Quarry*, Aug. 1954, **47**, 117–20. A comprehensive treatment based on performance tests. *See under* Cement.

1192. **Coal Breakage Processes v. Analysis of Closed Circuit Grinding.** BROADBENT, S. R. and CALLCOTT, T. G. *J. Inst. Fuel.* 1957, **30** (192), 21–5. The equations of a closed circuit (recirculating) grinding system are derived, and a matrix method for the steady state is given. The solution is verified in a system incorporating the Laboratory Cone Mill (4 in. diameter). The analysis required is more complex than that for open-circuit grinding, but the difficulties overcome are far greater. No other method of analysing such a system is known to the authors. The application of the method to industrial problems requires a thorough knowledge of the characteristics of the mill and of the classifier involved. Photographs, 14 refs. For other papers on matrix analysis, *see under* Coal.

1193. **Fine Crushing in Ball Mills Open Circuit Crushing.** DAVIS, E. W. *Trans. Amer. Inst. min. (metall.) Engrs*, 1920, **61**, 251–3. It is concluded from full-scale investigation that closed circuit crushing will always have the advantage over open circuit crushing, in that the maximum size particle produced will always be nearer the average size. This is a desirable condition, since the size of balls making up the charge must be computed on the maximum size particles in the feed rather than on the average size. Pages 253–94 of this paper are noted under Ball and Tube Mill Theory. [P]

1194. **Grinding in a Closed Circuit.** HITZROT, H. W. *Chem. metall. Engng*, 1938, **45**, 234–5, 243.

1195. **Comparison between Open and Closed Circuit Dry Grinding in a Laboratory Ball Mill.** LIFLYAND, D. N. and TUNTZOV, A. G. *Inst. Mekanicheskoi Obrabotki Poleynuykh Iskopaemuykh 'Mekhanobr.'* 15 *yr. Socialistic Ind. Service*, 1935, **1**, 256. The closed cycle mill gave more useful capacity, and less overground material. Experiments were made on quartz and apatite to determine comparative efficiency. A charge by 12% by volume of the mill gave the best results in both cases. [P]

1196. **Closed Circuit Grinding.** PERRY, J. H. *Chemical Engineers Handbook*, 1950, pp. 930–7. Many aspects of closed circuit ball mill grinding are discussed, including wear and power consumption. A section deals with cement raw material grinding.

1197. **Grinding Experiments with an Air Swept Tube Mill.** ROSIN, P. and RAMMLER, E. *Ber. Reichskohlenrates*, C.50; *Arch. Wärmew.*, 1932, **13**, 63. Characteristics of various designs of air-swept tube mills with circulating and open circuits. Grinding experiments with pre-dried coal and mill drying systems. Experiments with different grinding media. Use of tube mills with air classifier for unit firing. [P]

1198. **Comparison between Open and Closed Cycle of Wet Grinding in Laboratory Ball Mills.** TUNTZOV, A. G. *Inst. Mekhanicheskoi Obrabotki Poleynuykh Iskopaemuykh 'Mekhanobr.'* 15 *yr. Socialistic Ind. Service*, 1935, **1**, 302. Iron ore and quartz were used for the experiments. The closed cycle mill had twice the useful capacity of the open cycle mill of the same capacity size. In both cases, the optimum conditions were 85–90% critical speed, a ball charge of 45–50% mill volume, an ore charge of 12% mill volume and an equal volume of solid and liquid.

1199. **Improvements in Tube Mills.** VAIL, R. H. *Rock Prod.*, 1921, **24** (9), 39. According to the writer, the closed-circuit system of grinding and air separation have increased the grinding capacity of tube mills from 15 to 25%. The advantages are fully discussed.

WET V. DRY GRINDING

1200. **Dry or Wet Grinding?** ANON. *TonindustrZtg*, 1936, **60**, 6. Two sets of experiments with normal sand were run, one with 0–10% water, the other with 25–65% water, in a laboratory ball mill. Curves are given showing that, for a given grinding period and the usual finenesses, wet grinding gives better results than dry. Optimum conditions are indicated at about 55% water.

1201. **New Grinding Theory Aids Equipment Selection.** BOND, F. C. *Chem. Engng*, 1952, **59** (10), 169–71. Discussion of dry v. wet grinding. Dry grinding in tumbling mills requires approximately one-third more power than wet grinding. Fan power is much more than that necessary for a rake classifier of a wet closed circuit mill. But in dry grinding, wear is only about one-fifth that in wet grinding. Appraisal is facilitated by the author's new grinding theory; cf. Fahrenwald, 1931, efficiency of wet grinding less than in dry grinding.

1202. **Grinding Hard Ceramic Materials.** CARINI, F. *Rev. Matér. Constr.*, 1946 (366), 54. Some points of contrast between the processes of wet and dry grinding are discussed, and a comparison is made between the Alsing cylinder and ball mills in respect of power consumption and the degree of fineness of the finished product. The author stresses the need to determine the exact amount of water to be added to a given material, and the way in which duration of grinding may be prolonged in order to reach a given fineness if this precaution is not taken.

1203. **Researches into Wet Grinding Hydraulic Binders.** CHASSEVENT, L. *Chim. et Industr.*, 1947, **57**, 327. Compared with dry grinding, wet grinding offers the advantages of simplicity and economy in the manufacture of blast furnace slag cements. *See under* Cement.

1204. **Ball Mill Grinding.** COGHILL, W. H. and DE VANEY, F. D. *Tech. Pap. Bur. Min.*, No. 581, 1937, 56; *Chem. Abstr.*, 1938, **32**, 4832. Detailed results for ores under different conditions. Concluded that wet grinding of ores gave 39% more capacity and 26% more efficiency than dry milling. Very hard nickel-chromium alloy martensitic iron balls were better than ordinary forged steel balls, particularly with very hard ore. The efficiency of battered rejected balls was 11% less than that of new spherical balls. Conclusions not necessarily valid for all classes of ball and tube milling. [P]

1205. **Mechanism of Grinding Fine Quartz Grains in Ball Mills.** KLASSEN, V. I. and POPOVA, E. I. *C.R. Acad. Sci., U.R.S.S.* (*Dokl. Akad. Nauk., S.S.S.R.*), 1952, **85** (1), 149–52. In a laboratory ball mill, using balls 135 mm diameter, dry grinding is most effective when the balls occupy only 20% of the mill volume. For wet grinding, about 50% is best, the sand charge being nearly three times as great as in dry grinding. Dry grinding proceeds intermittently, at first intensively, then slowly, and finally with great speed. The mechanism is discussed.

1206. **Grinding Fundamentals.** MAXSON, W. L. *Chem. metall. Engng*, 1938, **45**, 226–9. The conditions governing dry and wet grinding, notably in rotating cylinders (i.e. pebble and ball) mills, are discussed.

1207. **Calorimetric Method for Studying Grinding in a Tumbling Medium.** SCHELLINGER, A. K. *Min. Engng, N.Y.*, 1951, **3**, 518–22. Peak thermal efficiencies for wet and dry grinding were found to be similar. *See* Nos. 145–6.

1208. **Tests on the Hardinge Mills.** TAGGART, A. F. *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1918, **58**, 126, 177. Includes a statement that the relative mechanical efficiency in wet crushing is decidedly greater than in dry crushing. *See also* No. 170.

1209. **The Theory of the Tube Mill.** WHITE, H. A. *J. chem. Soc. S. Afr.*, 1905, **5**, 290. Gives a mathematical discussion of ball paths. In dry pulp, the pulverizing action is due almost entirely to impact, but with the mill half full of water, the reduction is due largely to grinding between the balls and very little to impact. *See also ibid.*, 1915, **15**.

HIGH V. LOW DISCHARGE

1210. **Comparison of Low v. High Discharge for Ball Mills.** HOLLINGER MILL STAFF. *Trans. Canad. Min. Inst.* (*Inst. Min. Metall.*), 1937, **40**, 85–109, Discussion, 327–31; *Canad. Min. metall. Bull.*, No. 298. Conclusion from tests: at a slightly lower power consumption per ton and at a lower overall cost per ton, a low discharge mill will grind more tons of ore to a given fineness than will a high discharge mill of the same size. Various factors investigated and tables of data are given. Wear on balls is investigated and illustrated. The Haultain infrasizer is tested. *See also* Nos. 1067 and 1077.

VISCOSITY OF FLUID MEDIA

1211. **The Effect of the Solid–Liquid Ratio on Grinding a Ceramic Nonplastic.** SCHWARZWALDER, K. and HEROLD, P. G. *J. Amer. ceramic Soc.*, 1935, **18**, 350. An electric-furnace mullite, previously ground to pass an 8-mesh screen and of sp. gr. 3·04, was wet-ground with solid–liquid ratios of 2·7 to 1 and 1 to 15 for various lengths of time. Grain-size distribution and surface area, determined by the Wagner turbidimeter method, were compared. The material ground with the least water gave a lower percentage retained on a 325-mesh screen, fewer particles between 10 and 60 microns, and more between 0 and 10 microns.

1212. **Particle Size Studies.** SCHWEYER, H. E. *Industr. Engng Chem.* (*Industr.*), 1942, **34**, 1060–4. Particle size distributions in the subsieve ranges have been used to study the development of surface and the decrease in top size in pebble mill operations using fluid media of different viscosities. Sand was used as a basis for these tests. It was found under the conditions used that the development takes place in two stages. In the initial period the rate of surface development is essentially constant and is a

function of the viscosity of the medium. In the second period the rate decreases and is practically independent of the viscosity of the medium. The rate of decrease of top size was found to be rapid at the start but decreases with time of grinding and is a function of the viscosity of the fluid medium used. In the first period the development varied between 50 and 1000 sq. cm per g per 1000 revolutions for a variation in viscosity between 401 and $1 \cdot 8 \times 10^{-4}$ centipoises. 14 refs.

VACUUM BALL MILL

1213. **Vacuum Ball Mill.** ELINSON, M. M. and CHRISTYAKOV, F. M. *Fact. Lab., Moscow* (*Zavodskaya Laboratoriya*), June 1949, **15**, 749. A mechanically operated ball mill in which crushing can be carried out *in vacuo* is described in this paper. The gases are pumped off for measurement and analysis.

1214. **The Gases Locked up in Coal.** FISCHER, F., PETERS, K. and WARNECKE, A. *BrennstChemie*, 1932, **13**, 209–16; *Fuel, Lond.*, 1933, **12**, 154. The authors have ground coal to less than 10 microns in a 'mu' mill. This is a very short-length ball mill, 24 cm diameter, and about 2 in. between centres of plates, revolving about a horizontal axis. The mill contains six 1½-in. steel balls moving centrifugally in the shaped periphery (ring and plates), and operating under vacuum at 1–3 mm pressure. In 16 hours' grinding coal was reduced to less than 10 microns; but at a lower pressure, 0·1–1·0 mm, the time was reduced to 8 hours.

1215. **Grinding Ceramic Materials in Ball Mills in a Vacuum.** VIRO, S. E. *Keram. Sbornik*, 1941 (15), 34; *Ceramic Abstr.*, 1942, **21**, 65. A vacuum has practically no effect on the grinding efficiency of ball mills using either the dry or wet method.

MILL LINERS

1216. **A Special Ball and Tube Mill Liner Plate.** ANON. *Edg. Allen News*, 1950, **29**, 661; 1951, **30**, 55. The Henricot liner plate discussed is made with a studded face so that distortion of the manganese steel by impact is more or less confined to the face without affecting the sole plate. In a stepped liner the grinding media are cascaded along a line parallel to the axis of the mill and cause local wear. In the Henricot plate the blows are distributed all over the plate on each stud head. Advantageous features claimed include: concentration of hammering action on wearing part of plate; suppression of trouble owing to spreading; advantage retained of a plate base of ductile steel; lighter weight of plate per sq. ft of area than standard plates; increased grip of material and grinding media over whole area of liners by stud formation; elimination of wasteful 'slip'; increase of linear life, reduction of liner renewal charges and 'standing' hours of mills; and overall improved grinding efficiency. 2 figs.

1217. **Liners for Ball and Tube Mills.** ANON. *Edg. Allen News*, 1951, **30**, 1010. In general, alloy steel liners have the longest life, but for larger balls and heavy impact shocks, manganese steel liners are usually recommended; *ibid.*, 1953, **32**, 368. Manganese steel is still being used, but tends to be replaced by alternative irons and steels which can be worked more readily. The applications in various types of mills are illustrated.

1218. **Materials to be Ground, Lining Brick, Alsing Cylinders.** ANON. *Keram. Rdsch.*, 1938, **46**, 361; *Ceramic Abstr.*, 1942, **21**, 240. Practical suggestions are given for lengthening the life of linings and cylinders and increasing efficiency.

1219. **The Problem of Wear (in Ball Mills, Slime Pumps and Flotation Plant) at the Ramsbeck Mill.** ARNOLD, O. *Z. Erzbergb. Metallhüttenw.*, Feb. 1954, **7**, 65–8. The mill grinds PbS and ZnS containing ores. The Hardinge conical mills have ribbed liners of plate-and-wedge-bar type and an analysis has been made of the economics of using liners made from: (1) grey C.I., (2) unalloyed steel with hardened surfaces, (3) composite liners of unalloyed steel with hardened steel cover plate, (4) a manganese steel containing Mn, 12–14% and Cr, 1·5%. Results show that with regard to wear and

costs, (3) and (4) are to be preferred, (4) having a slight overall advantage. Tables, diagrams.

1220. **Reduced Wear in Tube Mills (and Ball Mills) by a New Design of Plate.** Bellwinkel, A. *Zement-Kalk-Gips.*, 1953, **6** (12), 439–44. The plates are provided with large closely-spaced conical studs. These are the Belgian 'Henricot-Mahlplatte mit Nocken'. Their use and the mechanism of ball travel are described, and wear data for cement grinding are given. Illustrations.

1221. **Wear Resistance of Domestic Materials for Pebble Mill Linings.** Berry, C. E. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 177–84; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1948; *Min. Tech.*, 1946, **10** (2). Belgian silex became unavailable early in the war, and a study was made on domestic substitutes already on the market in large quantities. Belgian silex was compared with a Minnesota quartzite, three granites from the Carolinas, two white porcelains, and white silica pebbles. Abrasion and toughness were tested by standard A.S.T.M. methods. A pebble mill grinding test and an acid-resistance test were run. He concludes that quartzite and granite are satisfactory substitutes for Belgian silex for pebble-mill linings. Granite is less desirable than quartzite because of colour contamination when wet-grinding white pigments. Porcelain appears to be the best substitute for silex from the standpoint of colour contamination. Silex is subject to attack by phosphoric and hydrochloric acid. 3 refs.

1222. **Present Day Grinding.** Djingheusian, L. E. *Trans. Canad. Min. Inst. (Inst. Min. Metall.)*, 1949, **52**, 243–57; *Canad. Min. metall. Bull.*, 1949, **42**, 555. Data on liner wear is given. There is no standard practice. Howes said that mill performance and liner life depend on liner design. Slippage is the major cause of liner wear and loss of grinding capacity. Improved design would also save ball wear, besides reducing liner consumption by 45%, and would save power. The Lake Shore Mines prefer circumferential grooves which give 17% greater capacity.

1223. **Martensitic White Iron.** Doyen, M. P. *Rev. Matér. Constr.*, Jan. 1950, 21–3. The application is discussed of a martensic alloy white iron of Ni-hard composition for the construction of mill liner plates. The superiority of this material is well known, but the paper contains new data of interest to workers in cement, ore, coke, refractories and paint industries. Examples are given of its resistance to abrasion in comparison with other alloys.

1224. **Double-Step Liner for Ball Mills.** Howes, W. L. *Engng Min. J.*, 1942, **143**, 57; *Ceramic Abstr.*, 1942, **21**, 192. The object is to reduce ball slippage to a minimum without interfering with ball action. The cross-section of each liner section is that of two trapeziums, each with two right angles on the side toward the retreating balls. The lifter should be about one ball diameter in width on top and about half as thick. The valley should be slightly over one ball diameter in width and shaped so that the balls will not be wedged in it. Bolts are usually placed in the valley between the lifters. Wear is concentrated on the lifters and not in the valleys. The same design can be used in end liners. Results have shown a saving of 20–46% in liner cost per ton of ore ground.

1225. **Ball Mill Liners.** Howes, W. L. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1577, 1943. (1) It was found that performance and liner life are substantially dependent on liner design. (2) Slippage was found to be a major cause of rapid liner wear and loss of grinding capacity. A design of double step liner was developed based primarily on the size of balls used (*U.S. Pat.* 2274331). A double step liner saved consumption by 45%, equiv. to 28 tons of manganese steel per year in 3 ball mills. Less ball wear was observed. Solid block liners had worn out in 100 days. Liners with undulating surface wore out in 60 days. Stepped fashion liners lasted up to 200 days. The size of step allowed the ball thereon to check the ball above.

1226. **Considerations of (Grinding) Mill Liners.** Howes, W. L. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1795, 4 pp.; *Min. Tech.*, 1945, **9** (2). Mill-liner design and loading are

discussed. Most of the liner wear occurs by attrition due to slippage at the toe of the charge. Increasing the liner thickness by 1 in. reduces the grinding capacity by 5%. A study of mill efficiency is facilitated by recording power consumption and throughput.

1227. **Boltless Cylindrical Mill Lining.** McINTYRE, E. D. *Engng Min. J.*, 1934, **134**, 25. The liner shape can determine whether the action is cascade or cataract.

1228. **Hardened Cast-Iron Alloys for Ball Mill Linings.** MAKH, V. G. *Fireproof Mat., Moscow* (*Ogneupory*), 1947, **12**, 86. Hardened cast-iron alloy linings are less durable than manganese steels but are equal to carbon steels in performance. They can be manufactured more cheaply than manganese steel linings. The composition and type of structure giving the best results, and the casting technique giving such a structure, are described. 1 table.

1229. **Grinding Pebbles and Tube Mill Liners.** METCALF, R. W. *Inform. Circ. U.S. Bur. Min.*, No. 7139, Nov., 1940.

1230. **Steels for Refractory and Heavy Clay Industries.** MILES, G. W. and KEITH, W. B. *Edg. Allen News*, 1954, **33** (379), 1–4; (380), 28–30. Austenitic steel has long been used for the manufacture of jaw crushers, and other heavy duty breakers. Equipment is described for the clay industries based mainly on this steel. It shows up unfavourably, however, in one application. This is in ball mill liners, where spreading occurs under impact and puts a strain on the fixing bolts. A table presents the behaviour of several steels when used for jaw crusher service.

1231. **Notes on Ball and Rod Mill Liner Practice in the Noranda Organization.** NORANDA MINES STAFF: AMES, H. L., PALMER, R., RICHARD, S., WEARING, T. and McLACHLAN, C. *Trans. Canad. Min. Inst.* (*Inst. Min. Metall.*), 1950, **53**, 423. 28 ball and 1 rod mills are used. All are overflow type, with cylindrical shells and dished heads. Sizes from 5 × 14 to 8 × 8 ft. A detailed account of liner practice is given, and of wear for a number of mills. The wear varies from 0·124 to 0·428 lb per sq. ft per day, depending on which part of the lining is considered, duty, size of mill, material and design. For the balls the average is between 0·13 and 0·24 lb per sq. ft per day. [P]

1232. **Cement Grinding Mill Liners.** SLEGTEN, J. A. *Rock Prod.*, 1949, **52** (2), 118; *Amer. Ceram. Abstr.*, 1951, **34**, 89. Various alloy steels were tested, including Cr, Mn, Mo, Ni and Si. Steel containing 12–14% Mn and 1·5% Cr shows less deformation and good abrasion resistance.

1233. **Ball Mill Problems.** SLEGTEN, J. A. and SLEGTEN, P. *Zement-Kalk-Gips.*, 1954, 7 (6), 241–9. Results of wear and creep tests are given of eight varieties of steels produced in electric furnaces for mill plates of ball crushers. Work done in 1934. Manganese steel with chromium additions are found to give the best performance. Design questions of milling plates are discussed. An important factor is the correct ratio between specific surfaces of the quality of the grindings and the mill body. Data given to verify this statement. Authors' fundamental research is verified by experience obtained in practice. No conclusion is drawn by the author as to the superiority of 'open' or 'closed' circuit mills which he discusses. [P]

1234. **Pebble Mill Linings.** TWELLS, R. *J. Amer. ceram. Soc.*, 1930, **13**, 669. The advantages and disadvantages of linings made of flint, quartzite, porcelain, and rubber are discussed. A comparative study of costs showed that porcelain gave the lowest cost per year of service. The high initial cost of rubber is its chief disadvantage, but it might be used for special purposes.

RUBBER LINERS

1235. **Solid Rubber Construction in New Ball Mill.** ANON. *Chem. Age, Lond.*, 3 July 1948, **59**, 10. A mill constructed with two rubber-protected end plates connected with steel tie rods over which are threaded rings of rubber, the whole assembly being held

together in compression by end mats. The more rapid reduction of the charge is attributed to improved cascading of the balls against the sides of the shell.

1236. **A New Rubber Ball Mill.** ANON. *Rubb. Developm.*, 1948, **1** (4), 30. The new 'Linatex' Ball Mill, which is claimed to be superior to earlier models, has a body made entirely of compressed rubber, thus obviating the difficulty sometimes found in securing the lining against the heavy load in shear caused by the grinding charge in action on the actual bond to the metal. With this mill the charge on highly abrasive materials, such as vitreous enamel frits, has been reduced more quickly than is possible with other grinding methods. The use of rubber in compression represents the ideal conditions for maximum durability. Mills are in three sizes and run at 25–52 rev/min for use with balls or steel, porcelain or selected flint pebbles, and are silent in operation. 1 fig.

1237. **Increasing the Efficiency of Fine Grinding.** BANKS, H. R. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 170–6; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1890; *Min. Tech.*, **9** (5); *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1945, **9** (11), 330. A ball mill is often operated with balls large enough to crush the largest fragments in the feed, though these may amount to less than 5% of the whole. The use of smaller balls increases the throughput of fines, usually by an amount varying as to the increased grinding surface present. Rubber lining of mills cuts down power consumption, but reduces production by an even greater amount. In general, rubber lining is uneconomic despite saving in wear. Cascade mills, in which no balls are used, are suitable only for certain types of ore.

1238. **Enamel Milling.** BENNETT, R. W. H. *Found. Tr. J.*, 3 June 1954, **96** (1970), 639–44. The paper deals with the requirements of pebble mills generally, then with the characteristics of enamel milling and the use of rubber-lined mills. Factors promoting mill efficiency, pebble size and grading, frit loading and water content. Mill linings of orthodox type are compared with rubber mill produced by the author's firm, the Linatex ball mill. This consists of a shell built up from rubber rings and tie rods, and can be mounted in the ordinary way. Data on mill speeds, diameter, charge are presented graphically and a loading table included. A very long life is expected from rubber mills and a freedom from contamination of product.

1239. **Rubber Linings for Grinding Mills.** FRITZ, H. E. *Crush. & Grind.*, May–June 1932, **1**, 163–4. A new easy way to install a rubber lining. A compound called Linerite has been found suitable. Diagrams of fittings are presented.

1240. **Practical Dissertation on Pebble Mills.** LAWLER, E. W. *Ceramic Ind.*, 1924, **2**, 369. The paper deals with contamination of potters materials and methods of avoidance, e.g. by lining the manhole with rubber instead of with porcelain or silex. The whole mill could with advantage be lined with rubber. No sign of rubber wear had been found in a particular mill after grinding a thousand tons. The advantage and costs of rubber lining are compared with those of conventional materials.

1241. **Rubber as Lining for Grinding Mills.** ROGERS, B. W. *Industr. Engng Chem. (Industr.)*, 1927, **19**, 139. Has been found useful in the ceramic industry; the wear is so slight that no contamination results.

1242. **Rubber Linings for Ball Mills.** SWINDEN, N. *Crush. & Grind.*, Nov.–Dec. 1931, **1**, 83. It is claimed that the capacity of a 4×2-ft mill is increased 15% with rubber lining; because slippage is reduced, 8·8% less wear per ton ground was obtained. Difficulties are found in sticking rubber to shell.

1243. **Grinding and Sifting.** TUBMAN, F. de M. *Chem. & Ind. (Rev.)*, 1932, **51**, 330. Rubber-lined mills grind as effectively as those with metal liners.

BALL AND PEBBLE MEDIA

1244. **Quartz Pebbles for Ball Mill in Saskatchewan.** ANON. *Engng. Min. J.*, 1943, **144** (4), 71; *Ceramic Abstr.*, 1943, **22**, 158.

1245. **Ni-hard Balls Beat Steel 4–1 in Cement Clinker Grinding.** ANON. *Nickel Topics*, 1954, 7 (4), 1; (7), 5, (8) 10. Wear resistance is of value in hammer mill liners.

1246. **Ni-hard Balls for Coal Pulverization.** ANON. *Nickel Bull.*, 1944, **17** (10), 147.

1247. **Casting of Grinding Balls.** O.T.S., U.S. Dept. Commerce, Washington, IR 10522, 1953, 4 pp. Obtainable in microfilm or photostat form from: Lending Library Unit, D.S.I.R. Price 2*s*. 6*d*.; enlarged prints 4*s*. The Payne Process for the automatic continuous casting of grinding balls is discussed with a description of the machine and statistics of costs and performance. The advantages claimed are listed. The report includes information about the type of steel to be used with its analysis and price, and a diagram shows the method of filling the moulds. Output 6–10 000 lb/h.

1248. **Natural-Shape Grinding Media.** ANON. *Paint. Varn. Prod. Mgr*, 1951, **41** (7), 24. These natural-shape grinding media are said to increase the dispersion rate of paint pigments in pebble mills by as much as 40%. The media are made of high-density alumina ceramic material, pure white in colour, shaped to simulate the shape of spherical balls after they have been flattened by wear in the mill.

1249. **The Influence of Size and Shape of Grinding Media.** ANON. *Rev. Matér. Const. (C)*, 1954 (463), 101–7. Extreme fineness is attained only if grinding members are small. Large balls lead to plaquettes of very fine particles (overgrinding). The form of grinding members does not affect the product.

1250. **Increasing the Efficiency of Fine Grinding Data from the Sullivan Mine is Presented.** BANKS, H. R. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 170. Some details of performance in a Hardinge 10 × 4-ft mill with various ball media are given. [P]

1251. **Sea Washed Pebbles for Fine Grinding.** BRAY, A. *Mine & Quarry Engng*, 1951, **17**, 402. Flint and chert pebbles from the South Devon coast shingle banks. Half-inch diam. pebbles are collected for pigment grinding and up to 3-in. diam. for general grinding.

1252. **Modern Methods in the Production of Porcelain Grinding Balls and Lining Blocks.** CARWOOD, R. L. *Industr. Engng Chem. (Industr.)*, 1931, **23**, 865–7. Balls are cut from extruded clay rolls (after ageing) and spun under great pressure. Then they are humidity dried. Lining blocks are made by the dry-press process. Illustrations.

1253. **Notes on the Use of Granite Tube Mill Pebbles in Nundydroog Mine.** CHOLMELEY, F. N. *Bull. Kolar Gold Fld. Min. Soc.*, No. 79, *Oregum, India*, Oct. 1952, **16**, 59–80. These made possible the grinding of coarser stamp mill products without any reduction in tube mill capacity, the cost being reduced by 10%. Cost comparisons and performance data are given. [P]

1254. **Screened Ore as Pebbles in Fine Grinding.** CROCKER, B. S. *Min. Mag., Lond.*, 1954, **40** (5), 309–10; *Canad. Min. metall. Bull.*, Mar. 1954. Results from tests in a 16 × 5-ft tube mill are: Capital cost of conversion from conventional ball mill can be saved in one year. A 16 × 5 ft high discharge mill is equal in capacity and power to 16 × 6 ft 8 in. grate discharge pebble mill. For −8 mesh material, the shape of the grinding medium is not important. The capacity is directly proportional to the sp. gr. of the media. Pebble consumption was 3·2% of tonnage milled, at Lake Shore Mines. Other conclusions are presented, 15 in all.

1255. **Paint Grinding Balls Made of Improved Alloy Cast Iron.** DE LONGE, K. A. *Paint. Varn. Prod. Mgr*, 1950, **30** (9), 17, 22. Cast iron containing 4–4·75% Ni and 1·4–3·5% Cr is used for making balls for ball milling. Although of the same hardness as hardened steel, the alloy ball wears better on account of its iron carbide content. Pastel shades may be ground with these balls without fear of discoloration.

1256. **The Working Principles of Ball Mills for Fine Grinding.** ENGELS, K. *Metall.*, 1954, **8** (3/4), 102–7. It is suggested in this paper that balls for grinding hard materials

should be made of tough rather than hard material. The penetration of the surface by grains of the hard product is likely to reduce wear of the iron.

1257. **McDonald Cubes as a Grinding Medium.** FAIRCHILD, D. H. *Engng Min. J.*, 1924, **117** (1), 865–6. The media are cubical but with rounded edges and corners and the purpose was to utilize not only point contact as with spheres but also line contact as with rods, and plane surface contact. Unnecessarily fine grinding as with point contact would be lessened. Cubes removed from the Moctezuma Copper Company Mill at Nacozari showed remarkable regularity in wear, retaining the cubical shape, although having acquired defects. The Company has been using these media instead of rods, and tests indicate a greater efficiency of the cubes over balls. Illustrated.

1258. **Grinding Balls.** FARREN, E. F. *Found. Tr. J.*, 1949, **87**, 155; 1950, **88**, 573. A method is described for producing 3-in. diameter cast iron balls used in grinding quartz rock in a ball mill. 5 figs.

1259. **A New Grinding Medium. Corundum.** FAURE, J. F. *Chim. et Industr.*, June 1954, **71** (6), 1202. Describes the advantages of corundum as lining and grinding media. Hardness 9 as compared with 7 on Moh's scale. Reports equivalent performance using one-tenth the weight of corundum balls, as with porcelain, presumably owing to a specific gravity of 3·2 for corundum as compared with 2·3 for porcelain, giving about twice the effective density difference between the balls and the wet pulp. This permits an increased charge and a 50% increase in product. The higher density can also permit smaller balls to be used.

1260. **Alloy Cast Iron Balls Cut Cost of Pulverizing Anthracite.** FRICK, C. H. *Power* July 1944, **88**, 71. Ball wear was reduced by over one-half (down to 0·31 lb/ton of anthracite), when balls made of 94% white cast iron, 4·5% nickel and 1·5% chromium were used instead of forged steel balls.

1261. **Theory and Practice in Selecting Grinding Media.** HARDINGE, H. *Engng Min. J.*, 1927, **124**, 695–8. A discussion, with illustrations, of effect on particles of impacting bodies of various shapes and sizes and of the effect of angle of nip between these media. Spheres, cubes and flat surfaces are discussed. Emphasis is placed on what product is required, e.g. rods are the best granulators, they cannot get at the fines. Surface of balls is not the only question and is less important than concentration of load. Suggests the Hardinge conical mill with reversed air flow for coal crushing.

1262. **Determination of the Correct Time for Adding Grinding Media to Rotary Mills.** JACOB, K. *Silikat Technik*, 1952, **3**, 511. Information is given upon the problem of deciding when to add new grinding balls to ball mills. It is shown that efficiency of grinding is lower when an arbitrary decision on 'topping up' is made. An expression is deduced to indicate the exact time for ball additions.

1263. **Tennessee Copper Explores New Grinding Media.** LEWIS, F. M. *Min. Engng, N.Y.*, 1953, **5** (5), 491. Following mention of this subject in the annual Review, *Min. Engng, N.Y.*, **5** (2), 1953, 158, data are presented to show the success of replacing marble pebbles for steel balls, originally carried out to improve flotation of the crushed ore. [P]

1264. **Grinding Pebbles and Tube-Mill Liners.** METCALF, R. W. *Inform. Circ. U.S. Bur. Min.*, No. 7139, Nov., 1940. Previous to the war of 1939, grinding pebbles were imported into the U.S.A. from France and Denmark and silex liners were imported from Belgium. The only commercial producer of pebbles in U.S.A. is the Jasper Stone Co., Sioux City, Iowa; here the pebbles are artificially rounded. Quartzite pebbles occur on the Canadian shore of Lake Superior and Conception Bay, Newfoundland; certain Cretaceous limestones of the United States are flint bearing.

1265. **Some Grinding Tests with Spheres and Other Shapes.** NORRIS, G. C. *Trans. Instn Min. Metall., Lond.*, Feb. 1954, **63** (567), 197–209. A series of laboratory tests was

conducted to determine the relative efficiencies of the following shapes: sphere, sphere with six small flat faces, cube, cube-cum-octahedron, circular cylinder, circular disc. The cube and sphere were tested on a plant scale in parallel ball mills. It is concluded from the tests that the nearer the shape is to the sphere, the more efficient is the performance. The suggestion (Warnecke, 1948) that a cubical shape promotes greater efficiency was not borne out. The sphere was most efficient by important margins with respect to mill capacity, power consumption and rate of wear. Illustrated, 5 refs. Discussion in *ibid.* (570), May 1954, and (571), June 1954. There was general agreement but certain speakers stated that oddly-shaped slugs and pebbles of various shapes had been found as efficient in some cases as spheres, particularly for 8–mesh material, and that tests with mixed shapes had not been made. Contributed remarks by F. C. Bond and author's reply to discussion in *ibid.*, **64** (2), 69–73.

1266. **Preferred Size of Balls for Ball Mills.** OLEVSKII, V. A. *Min. J. Spb.*, (*Gornyi Zhurnal*), 1948, **122** (1), 30–3. Where the balls are of one size the following formula is derived for preferred size: $D_m \leq 6(\log d_k)\sqrt{d}$, where D_m is the diameter of the balls in mm, d is the upper diameter of feed in mm, and d_k is the diameter of the product in microns at 90% passing. A chart is given for reading values of 6(log *dk*). For balls of different sizes empirical corrections are necessary. Adjustments for balls of mixed sizes may be made by proportionality experiments, and for wear by corrections according to one of the known theories for wear of balls in continuously operating mills.

1267. **Casting Grinding Balls Continuously.** PAYNE, P. M. and STEINEBACH, F. G. *The Foundry, Detroit*, Mar. 1950, **78**, 70–3, 217–19. Description and illustrations of circular frame containing 36 water-cooled copper moulds and mounted on a turntable. Pouring is continuous, the moulds open and close at predetermined points and the small risers on the balls are removed automatically by cutting discs.

1268. **High Density Media Speeds Up Crushing for Laboratory Analysis.** PERKINS, W. H. *Power*, 1953, **97** (5), 80. A one-gallon ball mill half full of ¾-in. pebbles is suggested by A.S.T.M. for crushing 200 g of coal to −60 mesh. A detailed comparison of performance for 1800-c.c. and 5000-c.c. jars is given.

1269. **The Development and Properties of High Density Ceramic Balls.** REDD, O. F. *J. Canad. ceram. Soc.*, 1953, **22**, 132. The density was 3·3 as against 2·38 for standard porcelain balls. A 50% filling is recommended. Temperature is higher because power input is greater. This can be remedied by over-charging, but a water jacket is better. The time of milling as a result of higher density balls, and the amount of wear are discussed.

1270. **Efficiency of Grinding Media.** SCHOTT, O. *Concrete, N.Y.* (Cement Mill Section), 1934, **42**, 35. The sizes of balls in compartment mills are discussed, beginning at 60–100-mm balls. Sufficient space is necessary between the grinding bodies to allow passage of the material through the mill. Good steel balls wear uniformly, cast-iron balls do not, the smaller balls wearing more rapidly owing to the lower thickness of the hardened layer. *Cylindrical* grinding bodies having a length equal to diameter are the best media. They group themselves more effectively than cylpebs and possess a large grinding surface. Grinding bodies of mixed sizes should be used. They can be worn down 95%. The cost of cylindrical media is less than that of steel balls and cubes. To estimate accurately the wear of grinding bodies, the test should extend over a year.

1271. **Zirconium Ball Media.** TITANIUM ALLOY CO. *Ceramic Ind.*, 1942, **39** (6). Mill balls much heavier than the normal ceramic body, gears made of ceramics, condensers almost too small to see were in the Titanium Alloy Co., Niagara Falls, New York, exhibit. The mill balls having a density of about 4·7 are made of ZrO_2 and fired to 2750°F. The extreme hardness will increase the life of the balls while the extra weight should shorten grinding time and improve grinding quality.

1272. **Burundum Grinding Media.** U.S. STONEWARE CO. *Canad. Chem.* (*Process*)

Engng, Sept. 1950, 23; Sept. 1951, 755; *Ceramic Age*, 1950, **56** (24). Announcement of a new shape and type of ball 80% heavier than porcelain and much harder. The media of cylindrical shape do not readily deteriorate to spherical and tend towards rod mill action. A much larger grinding area is provided, and a 50% increase in production rate is claimed.

1273. **High Density Media Grinding Cuts Milling Time, Increases Liner Life.** VERNETTI, J. B. *Ceramic Ind.*, Mar. 1954, **62**, 70. Data are tabulated for some thirty tests with high density spherical media made of alumina of density 3·4 as compared with 2·5 for conventional flint pebbles. Enamel frit was ground with balls of various sizes. [P]

1274. **Milling Practices with High Density Balls—A Survey.** VERNETTI, J. B. *Proc. Porcel. Enam. Inst., Forum*, 1953, **15**, 62–5; *Finish, Chicago*, 1954, **11** (8), 45–6; *J. Amer. ceram. Soc.*, Oct., 1954, 175. Alumina balls, sp. gr. 3·4 (porcelain and flint balls 2·4) were found to have the following advantages: (1) reducing by up to 60% in grinding time; (2) consumption of balls decreased by 80% to 90% of consumption of porcelain balls; (3) charge temperature was reduced; (4) lining life was increased. More power supply is recommended. The work was done on enamel frits.

1275. **Flint Pebbles and Their Utilization.** VIE, G. *Industrie céramique*, 1950, 307, 1951, 1453. Flint pebbles are produced at the rate of 6500 cu. yd per year along a 17-mile strength of the French coast from Fécamp to Cap d'Antifer, and are used as grinding media in ball mills, in cement, and also in earthenware and refractory bodies. To reduce or eliminate the conversion expansion, they may be calcined at 1200°–1400°C or dead-burned at 1550°C. The purity compares well with that of Westerwald and Hesse quartzite.

1276. **Ball-mill Crushing Media.** WARNEKE, F. *Chem. Engng Min. Rev.*, 1948, **40**, 365–72. A theoretical treatment of the action of balls in a mill and of the behaviour of grinding media is given. A cylindrical mill charged with cubical steel balls and rotated at 65% of its crit. speed should effect more efficient size reduction of any material by the process of crushing rather than grinding. Digest in *Min. Mag., Lond.*, 1948, **79** (4), 246. *See* G. C. Norris, 1265, who finds the sphere to be the best shape.

1277. **Shaped Grinding Ball for Ball Mills.** WESTON, D. (Canada). *U.S. Pat.* 2558327, 1947. To avoid the disadvantages of a multiplicity of surfaces with consequent limited rotatability, and to increase the grinding area associated with a plain sphere, the present design is for a ball modified to give to a limited extent, cylindrical surfaces at right angles to each other.

1278. **Dense Random Packing of Unequal Spheres.** WISE, M. E. *Philips Res., Rep.*, Oct. 1952, **7** (5), 321–43. Dense random packing is defined in a new way in terms of a probability distribution function for tetrahedra. 9 refs. *See also under* Boerdijk.

BALL COATING

1279. **Ball Coating in Grinding.** BOND, F. C. and AGTHE, F. T. *Rock Prod.*, 1941, **44**, 58; *Build. Sci. Abstr.*, 1942, **15** (5). The authors have collected and correlated some available data on the occurrence and causes of dry coating of the balls and pebbles with the material being ground in a ball or tube mill. Soft materials (e.g. gypsum or bauxite) tend to coat at coarser sizes than hard or brittle ones: limestone coats more readily than silica, which usually passes 325 mesh before coating becomes serious, while granite and felspathic minerals alone usually tend to coat at 92%, passing 200 mesh. With cement clinker the small amount of moisture selectively hydrates the finest particles present and these are most effective in the coating process. Different clinkers, however, vary widely in their tendency to coat: rapid cooling of the clinker immediately after leaving the kiln appears to decrease coating. Laboratory tests, including microscopic observations and specific surface determinations, designed to study

the causes of ball coatings are described, and results indicate conclusively that coating is a mechanical process starting with particles 3–5 mil diameter which are tamped into the pits and scratches of the grinding surfaces by the impacting balls. The reduction of the amount of fines present or their retention in the ball scratches may be prevented by (1) the use of liquid dispersing agents, which, however, can only be used with certain specified materials, (2) the substitution of closed circuit grinding in place of open circuit, (3) the use of harder surface grinding media. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1160, 10 pp.; *Min. Tech.*, 1940, 4.

BALL WEAR

1280. **Cement Grinding Test Shows Ni-hard Balls Beat Steel.** *Inco Nickel Topics*, 1954, 7 (8), 10. The comparison was made in a $5\frac{1}{2} \times 22$-ft. clinker tube mill with 1-in. balls in closed circuit. The wear per barrel of cement was 0·14 lb and 0·04 lb for forged steel and Ni-hard balls respectively, after a run of nearly 300 000 barrels with each.

1281. **Wear and Size Distribution of Grinding Balls.** BOND, F. C. *Trans. Amer. Inst. min. (metall.) Engrs*, 1943, **153**, 373; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1191; *Min. Tech.*, 1940, 4, 12; *Ceramic Abstr.*, 1940, **19**, 241. The author examines the cause of wear of grinding media. He attributes the cause of faults in grinding technique to a lack of systematic investigation. The precise aspects on which investigation is needed are considered in detail. They include a rigorous mathematical analysis of size ratio between balls and particles, distribution of ball sizes, equilibrium ball charge and initial load and make up, residence time, contact area and selection, and the rationing of make-up balls according to size of feed. The wear varies as (ball diameter)$^{2 \cdot 21}$.

1282. **Abrasion of Porcelain Balls.** CHESTERS, J. H. *Nature, Lond.*, 1945, **155**, 485. A photograph shows porcelain balls which, after a few months' service in grinding refractory materials, have assumed a roughly cubic shape, and are approximately half the original size. They were made by extruding a cylindrical column, cutting this, and rolling the sections into spheres.

1283. **Induction Hardening for Ball Mills.** COVERT, S. A. *Metals & Alloys*, 1943, **17**, 349. Doubling the life of steel balls or cast-iron slugs in ball mills can be accomplished by induction hardening, such as the 'Tocco' process. Ball mills have extensive use in cement mills for grinding, but are also standard equipment in grinding ores, paint pigments, plastics, resins, etc. Slugs experience excessive wear during grinding. Frequently they crack, thereby clogging the ball mill meshes, or they pit, thus becoming coated with cement and ruining their grinding ability. In a cement mill, inductivity-hardened slugs showed a loss by wear of only 0·06 lb of steel per barrel of cement as against 0·13 lb lost by slugs hardened by older methods. Capacity of a typical induction hardening machine can be as high as 5000 slugs per hour. Slugs pass through an inductor coil on a roller feed and are immediately quenched in the same unit after being heated to the proper degree.

1284. **Fine Crushing in Ball Mills.** DAVIS, E. W. *Trans. Amer. Inst. min. (metall.) Engrs*, 1920, **61**, 284–7. A mathematical analysis of ball wear is included, conclusions are itemized and experimental data tabulated. [P]

1285. **Ball Wear in Cylindrical Mills.** DAVIS, E. W. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 147; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1736; *Min. Tech.*, 1944, **8** (7). A critical review of a paper by T. K. Prentice on the wear of steel balls used for grinding ores is presented. (See *J. Iron St. Inst.*, 1943 (II), 55A.)

1286. **Relation of Ball Wear to Power in Grinding.** DE VANEY, F. D. and COGHILL, W. H. *Engng Min. J.*, 1937, **138** (7), 337–40; *Ceramic Abstr.*, 1938, **17**, 30. Three sets of curves give data for the wear of steel rods, steel balls, and cast-iron balls in mills used for different ores. Pounds of ball material worn away per ton of ground material produced are indicated as well as pounds worn away per horsepower-hour. Skeleton

screen analyses of feed and finished material are given, and the plant or material is mentioned. The authors conclude that ball wear for loads of equal weight is independent of ball size. Ball wear for equal power input is independent of the speed of the mill. Wear in terms of power varies less than wear in terms of tons of ore ground. For steel balls, average wear is 0·15 lb/h.p.-h. If it exceeds this figure the ore is unusually abrasive.

1287. **Present Day Grinding.** DJINGHEUSIAN, L. E. *Trans. Canad. Min. Inst.* (*Inst. Min. Metall.*), 1949, **52**, 243–57; *Canad. Min. metall. Bull.*, 1949, **42**, 555. Data on ball wear at Lake Shore Mines is given. Bond found that ball wear varied as the diameter, to the power 2.21. Prentice found, within limits, rate of decrease in diameter was independent of diameter (within limits), that is, loss in weight varied with area. With continuous addition, the ball load reaches an equilibrium in size distribution ($\frac{1}{2}$ in. loss in diameter in one month). Garms and Stevens confirmed this and found segregation of sizes, the largest on the outside.

1288. **Ball Wear and Functioning of the Ball Load in a Fine-Grinding Ball Mill.** GARMS, W. I. and STEVENS, J. L. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1984, 4 pp.; *Min. Tech.*, 1946, **10** (2). Forged balls were tested in comparison with cast balls. To a mill having a normal load of cast balls, forged balls of 2 in. diameter were added daily. When the balls wore to 1·25 in. or less they lost their spherical shape. The balls are classified centrifugally according to size, with the new and largest on the outside and the size decreasing gradually to the centre. The largest balls do most of the impact crushing. The smaller balls are in the inside and grind mostly by attrition. The logic of ball-size rationing is more apparent. Ball diameter plotted against days shows a straight line. During the major portion of ball wear, a film of definite thickness is periodically removed from each ball, regardless of its size. 2 figs.

1289. **Ball Wear in Wet Grinding Mills.** MACLEOD, N. A. *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1946, **169**, 140–6; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1918, 7 pp.; *Min. Tech.*, 1945, **9** (6). Tests of 60–150 hours' duration in a rubber-lined cylindrical mill ($9 \times 10\frac{1}{2}$ in. in diameter) rotating at 72 rev/min with a charge of 2 kg of dry feed and 2 litres of H_2O, and using balls generally of 2 in. diameter, showed that the weight loss was lower with hard than with soft balls when grinding the same material, and for inert ores increased linearly with decreasing ball diameter. No definite effect of air when grinding siliceous ores could be established, but consumption of steel was lower when grinding pyritic ores under anaerobic than under aerobic conditions. It is considered that the highly abrasive character of pyritic ores is as much due to chemical as to physical causes. The grindability index is not a reliable guide to ball consumption, especially when comparing pyritic with non-pyritic ores.

1290. **A Contribution to the Problem of Ball Wear in Ball-Mill Grinding.** MORTSELL, S. *Jernkontor. Ann.*, 1940, **124** (1), 1–38; *Ceramic Abstr.*, 1941, **20**, 22. The author commences by pointing out the importance of the wear of balls in ball mills, especially with regard to the grinding of ores. He discusses Davis' theory that the wear of any one of a number of balls in a mill is proportional to its weight, and then describes his own tests, which show that the wear of a ball in a ball mill is directly proportional to the grinding time, and it is therefore constant per unit of time for each ball making up a 'charge' and is independent of its size. Some of these tests were carried out with forged and cast steel cubes of different dimensions, which were put in a ball mill for grinding iron ore for various periods of time up to 1700 hours. In other tests balls of three different sizes were used in a small laboratory mill for periods of about 400 hours. For comparison purposes the author uses the symbol μ to represent the coefficient of wear, which he defines as the reduction in diameter in thousandths of a millimetre per hour of continuous grinding. The results of these tests made it obvious that μ is constant for a charge of balls used for continuous grinding, and it is seen from this that the wear of any one ball is not proportional to its weight but to the area of its

surface. The introduction of the coefficient μ is very useful in the study of the efficiency of ball and rod mills, and it also provides a means of comparing and selecting balls of different qualities of steel. The author presents calculations based on the above relationship between ball wear and surface area by which the number and size of the balls required can be determined when μ is known. He considers next the causes of non-uniform wear of balls, and, as further evidence in support of his theory that μ is constant for all the balls of a particular charge without regard to their size, he quotes data respecting the size and wear of balls used in a cylindrical mill at the ore-concentration plant at Ronnskar (in North Sweden). He then discusses some investigations of Gross relating to the influence of the grain size of the ore on the wear of the balls, and, in conclusion, he shows that the results obtained by various investigators, which seem to support Davis' theory, do not in actual fact contradict the author's own theory that the total wear of a charge of balls is equally distributed over the total surface area of the balls.

1291. **Toward Decreased Ball Wear.** MORTSELL, S. *Engng Min. J.*, 1945, **149** (5), 90; *Ceramic Abstr.*, 1948, **31**, 225. Quartz (average grain size 0·078 mm and weighing 1·608 g) was ground in a small porcelain ball mill 19 cm in diameter and 15·5 cm long by 75 steel balls averaging 26 mm at 68 rev/min for 1 hour. The balls were then weighed, and the particle size of the quartz was determined. This was repeated without change in the balls or quartz for a total of 9 hours. Wear per unit of time increased rather rapidly up to a maximum, after which it decreased more slowly. Under these conditions the quartz that produced the greatest amount of wear had an average particle size of 0·017 mm. Wear can be reduced by removing these fine particles by a classifier or screen. 3 figs., 8 refs.

1292. **Wear Tests on Grinding Balls.** NORMAN, J. E. and LOEB, C. M. *Trans. Amer. Inst. min. (metall.) Engrs*, 1949, **183**, 330; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 2319; *Min. Tech.*, 1949, **12** (3). By running marked balls in a ball mill along with a group of standard balls of known quality, it is possible to determine the relative merits of any type of grinding ball within a short time. Barring segregation, grinding balls wear in direct proportion to their surface area and therefore decrease in diameter at a constant rate. A matrix of martensite or low-temperature bainite, plus retained austenite, has shown the best wear resistance of all the types studied. Spheroidized carbides enhance the wear resistance of a martensitic matrix. Test results on balls of other compositions are given. The relations between composition and wear resistance are discussed in great detail and experimental results are tabulated. Selection of alloying elements is exemplified. 1 fig., 15 tables.

1293. **Relative Wear Rates of Various Diameter Grinding Balls in Production Mills.** NORQUIST, D. E. and MOELLER, J. E. *Min. Engng, N.Y.*, 1950, **2**; *Trans. Amer. Inst. min. (metall.) Engrs*, **187**, 712–4. From the results of wear trials with copper ore using 4-, 3½-, 3- and 2-in. forged steel balls, it is concluded that balls in a given mill for a given length of time will have equal diameter losses, regardless of size. 4 figs., 2 tables.

1294. **Ball Wear in Cylindrical Mills.** PRENTICE, T. K. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 147–54; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1736; *Min. Tech.* 1944, **8** (4). A paper presented to the Chemical, Metallurgical and Mining Society of South Africa is abstracted at length and reviewed by E. W. Davis. To obtain experimental data a ball mill was operated at about 65% its critical speed; under these conditions grinding is by abrasion rather than by impact, and ball wear was proportional to the square of the diameter. The reviewer believes that at super-critical speeds, grinding is by impact and ball wear becomes proportional to the cube of the ball diameter.

1295. **Ball Wear in Cylindrical Mills.** PRENTICE, T. K. *J. Chem. Soc. S. Afr.*, 1943, **43**, 99–132. The author gives an account of an investigation, lasting fifteen months, of the wear of steel balls in a cylindrical ball mill used for grinding ores in the Transvaal gold mining industry. The mill used for the tests was 30 in. in diameter and 17 in. long.

Sets of balls 3 in. and 2½ in. in diameter were run continuously for periods of 5 days, 13½ hours each, the mill being revolved at 30·5 rev/min, after which the reduction in volume of the balls was determined; from this the number of days taken to reduce the diameter to 1 in. was calculated. The steel balls with the longest life were forged and contained: carbon 0·90%, manganese 0·89%, chromium 0·8–1·0%, with silicon, sulphur and phosphorus not exceeding 0·22%, 0·035% and 0·025% respectively; the hardness was 350–400 Brinell. The tests showed that the rolled balls with the best durability contained in all cases carbon 0·60–0·90%, chromium 0·85–2·1% or about 2·5% of manganese. In the second part of the paper a statistical analysis of the test results is made and from this a theory for the wear of balls in grinding mills is developed. The tests disclosed that while wearing down from 3 in. or 2½ in. to 1¼ in. in diameter, the loss of weight was directly proportional to the square of the diameter and therefore to the surface area of the ball; the subsequent wear from 1¼ in. downwards was relatively slower and more in accord with E. W. Davis' theory that the loss in weight is directly proportional to the cube of the diameter. (Critically reviewed by E. W. Davis.)

1296. **Gold Mining in the Witwatersrand.** PRENTICE, T. K. 1949, Transvaal Chamber of Mines, Johannesburg. Chap. III, pp. 127–30. Ball Wear in Cylindrical Grinding Mills. The causes of ball wear are analysed; the composition and wear resistance of 20 varieties of steel ball ore tabulated and formulae are given for equilibrium loads of balls. Distinction is made between ball wear due to impact on falling, and that due to attrition while en masse.

1297. **Factors in Relative Wear of Grinding Ball Sizes.** TIMMERMANS, O. E. B. *Engng Min. J.*, May 1947, **148**, 78. (1) Average ball wear was found to be proportional to the area per unit ball. (2) Wear is less when two sets of balls have equal surface area than when equal in volume of balls. (3) Effects of different sizes of ball are discussed.

1298. **On the Wear of Balls in Ball Mills.** YU BRAND, V. *Min. J. Spb.* (*Gornyi Zhurnal*), 1950 (4), 31–3. The value of a formula for ball wear in a mill grinding apatite is discussed. Results depart from the calculated values when the balls are split. Data are presented in 3 tables and 4 graphs.

VIBRATORY (OSCILLATORY) BALL MILLS

1299. **Grinding and Treatment of Minerals.** *B.I.O.S. Final Reports*, 1356 and 1753; *FIAT Final Report*, No. 754, 1946. H.M. Stationery Office. An account of the equipment and processes for grinding various minerals in Germany, and of the factories visited. The vibration ball mill made by Siebtechnik G.m.b.H. is given a harmonic vibration which makes the balls dance and rotate. Reduces various materials from silicon carbide to rice down to a size of 1 micron. Power consumption is claimed to be only 5% of the normal ball mill requirement. The vibration is by an out of balance shaft giving a harmonic vibration. The mill can produce 90% finer than 5 microns.

1300. **Novel Vibratory Ball Mill.** ANON. *Chem. Age, Lond.*, 1945, **52**, 367. A description is given of a ball mill of new design obtainable from Messrs Griffin and Tatlock, Ltd. The mill, which has a capacity of 250 g, produces 300 mesh or finer material and is suitable for the grinding of coal, coke, boiler scale, slags, etc. The pot does not rotate on its axis, the axis being caused to trace out a cylindrical path.

1301. **Vibratory Ball Mill for More Efficient Grinding.** ANON. *Tech. New. Bull. U.S. Bur. Stand.*, 1950, **34** (10), 140–1; *Ceramic Age*, 1950, **56** (6), 35; *Ceramic Ind.*, Nov. 1950, **50**, 62; *Min. Engng, N.Y.*, 1951, **3**; *Trans. Amer. Inst. min. (metall.) Engrs*, 1951, **190**, 122–5. The new laboratory mill described contains 3700 steel balls, and gives 100 000 collisions per second. It is claimed to produce a more uniform powder, to be more efficient and easier to operate than any previous mill; it is expected to have extensive application in the preparation of pigments, ceramic materials, metal powders, etc. A cylindrical jar is suspended by leaf springs and is swung through a circular path,

at the same time the jar counter-rotates slowly about its axis, and thus settling is prevented and more uniform grinding obtained. Vibratory motion is imparted by a ¼-h.p. motor which rotates an eccentric weight, to which the jar is indirectly attached, in a housing supported by the leaf springs. 5 g. of cotton are reduced in 30 minutes to a maximum of 10 microns.

1302. **Exploitation of Low Grade Ores in U.S.A. Chap. IV. Vibrating Ball Mill.** *O.E.E.C. Technical Assistance Mission*, No. 228, 1954. O.E.E.C., Paris. Obtainable from H.M. Stationery Office. Research on this mill has been taken up at M.I.T. and by Allis Chalmers. The advantage of this mill is its high capacity, which is said to be about seven times that of a conventional ball mill of the same size. The problem of the mill seems to be to get strong enough bearings for the unbalanced shaft. At the time of the visit a 42×42-in. vibrating ball mill, the biggest to date, had been installed for dry grinding of cement clinker.

1303. **(A) Grinding Process in Oscillating Mills with Dry Charge. (B) Grinding Process in Oscillating Mills with Wet Charge.** BACHMANN, D. *Verfahrenstechnik*, 1940 (2), 43–5, (3), 82–9. Development began in 1933 at Farbwerk Hoechst. Grinding experiments with marble suspensions (0·2 kg marble per kg water) are described. The progress of fineness of charge is found by following the settling line through glass windows, the fineness being read as a function of the fall of the settling line. *See Mon. Bull. Brit. Coal Util. Res. Ass.*, 1941, **5** (4), 79. [P]

1304. **The Development of the Vibratory Ball Mill.** BACHMANN, D. *Chem. Tech., Berlin*, 1942, **15** (9), 195–8. The development (from 1933) is described and illustrated by fourteen figures and diagrams of the trough mills made by I.G. and Krupp. Six literature and twenty patent references are given. A block diagram of performances is included. *See also* Meldau, *Z. Ver. dtsch. Ing.*, **76**, 1189. [P]

1305. **The Uses of Ball Mills in Grinding.** ENGELS, K. *Metall.*, 1954, **8** (3/4), 102–7. The construction, performance and uses of vibration ball mills are described. The advantages of both free swinging and induced vibration mills are described and since these mills are only at the beginning of their development, much more may be expected of them.

1306. **On the Mode of Action of Size Reduction Equipment.** GRUNDER, W. *Ber. dtsch. keram. Ges.*, 1938, **20**, 284. This correspondence recounts the showing of films at Wurzburg, in which Krupp's Symons Kegel brecher and the movement of the mass in ball and vibratory ball mills were featured. The fineness of the products from the vibratory ball mill indicated a marked advance in methods of size reduction.

1307. **Limits of Grindability of Coal in Ball Vibration Mills.** GRUNDER, W. and STUCKMANN, H. *Bergbau*, 1940, **53**, 107–12; *Feuerungstechnik*, 1940, **28**, 267. Good results were obtained up to 24 hours' grinding, after which further grinding produced coarsening.

1308. **Vibratory Ball Mills.** HAIM, G. and ZAID, H. P. *Brit. Pat.*, 596712, 1945/48. Provided with out of balance weights whose positions can be varied in radial or angular relationship.

1309. **The Development of Oscillatory Machines for Process Technology.** KIESSKALT, S. *Verfahrenstechnik*, 1936 (1), 1–4. The nature and purposes of vibrating or reciprocating apparatus for extraction, pulsation drying, vibration grinding, and gaswashing. A photograph illustrates the much finer product obtained by the oscillatory mill when ground under comparable conditions to the ball mill.

1310. **Vibration Mill.** KIESSKALT, S. *Z. Ver. dtsch. Ing.*, 1 July 1949, **91**, 313–5; *Amer. Ceram. Abstr.*, 1950, **33**, 18. An annotated literature review of the development of this mill; the mechanical process of grinding; mechanico-chemical and ultrasonic effects occurring during the pulverizing process; and the application to various industrial processes. The application to coal and coke is mentioned. A graphic pre-

sentation of performance at various speeds of a laboratory vibrating ball mill is given. 29 refs. [P]

1311. **Operation and Application of Small Oscillating Ball Mills.** Kramer, H. *Metall.*, 1950, **4**, 498–502; *Chem. Abstr.*, 1951, **45** (8), 3204b. These mills are especially adapted for the fine grinding of very small quantities of material. The theory and method of operation are discussed. The grinding is finer and faster.

1312. **Investigations on Oscillatory Mills.** Meldau, R. *Verfahrenstechnik*, 1939, 95–8. The suitability of this mill for very fine reduction is investigated. The procedure is outlined whereby shortly after commencing the operation a product of size 1 micron and less can be continuously withdrawn and passed out for further operation. The uniformity of size of product that can be obtained is shown graphically. The mode of action on particles and the surface effects on balls are illustrated and examples of size distribution of product from a few materials, e.g. ferro-manganese are given. 9 refs, the earliest being Meldau, *Z. Ver. dtsch. Ing.*, 1932, **76**, 1189.

1313. **Fine Grinding of Metal Dusts in Vibratory Mills and Their Microscopic Shape.** Olbrich, R. *Verfahrenstechnik*, 1942, 23–7. Compressed Al foil was ground for 10 hours in a laboratory mill (0·3l capacity, average amplitude 4 mm, frequency 24 Hz), (a) in the dry state in a hard porcelain grinding chamber with porcelain balls, and (b) in a steel chamber with Cr-steel balls with or without addition of fat or stearine. Granular particles were obtained in the porcelain chamber and lamellar particles in the steel chamber; the grinding efficiency was highest when using the latter, with addition of fat. No difference in particle shape obtained in both types of chamber was observed in the case of Ag solder.

1314. **Vibratory and Rotary Ball Mills.** Robinson, R. S. *U.S. Pat.* 2613036, 1947/52. The drawings show a rotating ball mill which can be vibrated at the same time horizontally and vertically by means of horizontal and vertical coil springs. The resulting advantages are described.

1315. **A Study of Vibration Milling on the Basis of Considerations of Dynamical Similarity.** Rose, H. E. Paper to the Institution of Chemical Engineers. London, 7 Nov. 1956. Although the mill has received an amount of experimental investigation, as far as is known the theoretical aspects of the problem have not been studied. An endeavour is made in this paper to analyse the milling process and with the aid of published results, to reach certain conclusions which are of interest in connexion with the choice of the best operating conditions for the milling of a given type of powder. The following conclusions may be accepted tentatively: (1) The rate of milling varies as a fairly high power of the frequency of vibration (the 5th power has been quoted elsewhere). (2) The rate also depends on a lower power of the amplitude, which is best kept reasonably small. (3) The amplitude should not be less than about twice the size of the largest feed particle, otherwise an excessive quantity of coarser material might be produced. (4) The rate of grinding varies directly as the density of the ball material, as their diameter, and as the diameter of the particle being ground, subject to (3) above. (5) It is probably independent of the volume of the ball charge, provided that the packing does not suppress the motion. (6) Over the range studied, the rate falls with increasing powder volume. It is probable that the maximum occurs with a powder charge lower than the ratio studied. Relations between variables are shown in 6 graphs, accompanied by mathematical analysis. 2 refs.

1316. **Comminution Studies in a Vibratory Ball Mill.** Rousselle, J. E. *Mass. Inst. Tech. Progress Report*, NYO–7172; M.I.T.S.–28, 31 July 1955, pp. 59–61; M.I.T.S.–29, 31 Oct. 1955, pp. 59–60. The influence on output of the feed rate and radius of vibration at two rotational speeds. Sand was ground in a 12 × 12-in. vibratory ball mill and the results shown as the amount of −200 mesh product per kWh. The results hitherto obtained show that increasing radius of vibration, feed rate and speed within the

operating range of the machine, increase the amount passing a 200-mesh sieve per kWh, and also the capacity (−200-mesh material per hour). In M.I.T.S. 30, 31 Jan. 1956, curves are presented, showing the increase of horsepower required for increased amplitude and also for rotational speed, and an equation is deduced for horsepower requirements in terms of these variables. It is shown that for times up to 10 minutes, the power requirements were not significantly greater with the mill grinding sand at 1300 lb/h, than when sand was absent.

1317. **The Ball Milling of High Molecular Materials.** Steurer, E. *Chem. Tech., Berlin*, 1943, **16** (1), 1–3. A review of the published work on the reduction of high molecular materials, with particular reference to cellulose. Electron microscope examinations, chemical action, viscosity charges, and energy balances are dealt with. 11 refs.

1318. **Improvements on, or Relating to Oscillating Mills.** Tema, Ltd. *Brit. Pat.* 696001, 1950/53. By periodically reversing the direction of the mill, for instance by reversing the direction of rotation of out of balance weights, the build-up at the sides is reversed, the wall is periodically cleaned, and caking due to one-sided build-up, is avoided.

1319. **Improvements Relating to Oscillating or Vibrating Mill with Air Separation.** Tema, Ltd. *Brit. Pat.* 698660, 1951/53; *Chem. Engng Progr.*, 1955, 36 (7), 270. Means are provided for air sweeping a vibratory ball mill, with air separation arrangements and return of oversize.

BALL MILLS, PAN OR VERTICAL CYLINDER WITH GYRATORY, CENTRIFUGAL AND/OR PLANETARY MOTION

1320. **Gyration Speeds Ball Mill Grinding.** Anon. *Chem. Engng*, 1955, **62** (12), 252. Capacities from four to seven times greater than usual are reported for a vertical, non-rotating, gyrating ball mill. The unit operates batch-wise or continuous, wet or dry. The gyration can be faster than the critical speed in a horizontal ball mill, and so output increases. The force on the balls also increases. If the ball load is increased to 70% of the mill volume, the radius of gyration decreased, and the speed increased, the load swells to completely fill the mill. The load no longer rolls or flows. Individual balls become highly energized and beat against each other. The centrifugal motion has the greatest grinding effect, however. No performance figures given for this Fahrenwald mill.

1321. **K.9 Steel for the Ceramic Industry.** *Edg. Allen News*, 1954, **33** (390), 268. The use of manganese steel is described for several types of clay working machinery. A laboratory mill suitable for the laboratory grinding of clay is described. It is a steel planetary ball mill, made by P. W. Heller, London. The mill consists of two equal eccentric masses, the jar mounted on a revolving platform and a counterweight. The mill is driven at 300 rev/min by a $\frac{1}{10}$-h.p. motor, will grind 70–90 c.c. of material, and contains two balls, whose rolling action on the wall of the jar, and by impact with each other, effects the reduction. Wear on the jar wall is avoided by absence of impact on the walls.

1322. **High Speed Laboratory Mill.** Anon. *Engineering, Lond.*, 10 Dec. 1954, 766; *Paint, Oil and Col. J.*, 26 Nov. 1954, 1232. Developed by a Stoke-on-Trent firm, it consists of four vertical cylinders revolving on a centre spindle, and each cylinder revolving itself in the reverse direction. Grinding capacity is 2½ pints per pot. Small balls are used and a turbulence is set up. It will grind and disperse a charge of colour pigment and medium in four hours as compared with forty hours in an orthodox ball or pebble mill. It will accomplish dispersions that have proved impossible by other means. The pots are interchangeable and the whole is mounted in a container with lid.

1323. **The Bloch Rosetti Design of Ball and Pan Mill.** ANON. *Min. J.*, 1953, **241**, 590–1. A type of laboratory mill by L. Hornuth, Heidelberg, for fine grinding, especially of ores, consists of a pan which imparts a centrifugal motion to the balls and charge without itself revolving. The drive is by $\frac{1}{20}$-h.p. motor at 300–800 rev/min as desired, and capacities of the three sizes of mill are 15, $\frac{1}{2}$, 0·183 cu. in. A fineness of one micron or less can be achieved, or even finer under special conditions. The improved mills described are: ball pan mills, disc mills with oversize return; jar crushers with two-way action, with 50% increased output, much lower crushing pressures, and uniform size of product.

1324. **Development of a Centrifugal Ball Mill.** CAREY, W. F., ROBEY, E. W. and HEYWOOD, H. *Engineering, Lond.*, 1940, **149** (3874), 378. Preliminary work was done in an attempt to construct a centrifugal ball mill employing all the advantages of 'free crushing', i.e. the crushing of a single layer of particles between metallic surfaces. The balls revolved in a vertical plane, the feed being applied to the centre of the mill and centrifuged outward to the balls. An air current removed fines from the opposite centre with return of oversize. Several engineering difficulties were encountered due both to the large surfaces required for grinding and to the difficulty of attaining a satisfactory radial distribution of the feed. Although no further work is contemplated, the authors believe that a satisfactory machine can be built.

1325. **The Spinning Ball Mill.** CLAUS, B. *Z. angew. Phys.*, 1955, **7** (12), 557–9. The construction is described of a new type ball mill exerting Coriolis force as well as centrifugal and gravitational force on particles. Gives higher grinding velocity, finer and more uniform product. 2 illustrations, 2 refs. The apparatus is a laboratory size, 1-litre ball mill, mounted on a horizontal axis but capable of being spun about a vertical axis from a shaft below; two wheels mounted on the extended horizontal shaft of the mill move around a rim at the same time and so cause the mill to revolve in the normal manner. The mill is one-quarter filled with 5-mm balls and at a very high speed of movement, the number of impacts is calculated to be 6×10^6 per second. No figures for fineness of product are given.

1326. **Improvements in Fine Reduction Mills and Method of Fine Reduction.** CROSS, E. J. *Brit. Pat.* 601608, 1945; *Trans. Brit. Ceram. Soc.*, 1949, **48** (1), 5A. An improved crusher where classification can take place at the same time. Ball elements are loose in a pan, set to rotate at an angle of about 15°. The charge is thrown clear of the base of the bowl to fall again. Only a limited amount of the charge is under impact at any one time.

1327. **The Uses of Ball Mills in Grinding.** ENGELS, K. *Metall.*, 1954, **8** (3/4), 102–7. The construction and performance of centrifugal ball mills is described. Much finer grinding 0·3–0·1 micron is accomplished in a shorter time, due to the energy and speed of revolution. Other advantages are the grain structure for similar technique purposes, and a narrow range of size frequency. The sticking of the fine product to the mill wall and methods of avoiding this (wet method) are examined.

1328. **New Type of Grinding Mill.** A. W. FAHRENWALD. *Rock. Prod.*, 1951, **54** (2), 93–7. Gyratory ball mill rotates on vertical axis for high rate of energy-input, thereby increasing effect of unit ball-load weight. (1) Two round containers are mounted on opposite sides of a vertical shaft around which they revolve whereby the contained balls tumble in ball mill fashion under the action of centrifugal force. (2) Another type is the gyratory ball mill in which the round box-like container gyrates on a rotating horizontal table. Tables and curves of test data are given. The gyratory mill is found to give several times the output of an equivalent gravity mill. [P]

1329. **The Gases Locked up in Coal.** FISCHER, F. *et al. BrennstChemie*, 1932, **13**, 209–16. *See under* Vacuum Ball Mill.

1330. **Gyratory Impact Ball Mill and Grinding Method.** SYMONS, L. G. *U.S. Pat.* 2500908, 1950; *Off. Gaz. U.S. Pat. Off.*, 1951, **632** (2), 611. The balls and rock partially

fill a suitably shaped pan, which gyrates around a vertical conical axis, the balls being thrown by the 15° inclination of the pan. Reduction and classification take place simultaneously, as the ball charge moves continuously to the lower portion of the bowl.

1331. **Gyratory Ball Mill having a Gyrated Chamber with a Peripheral Discharge.** SYMONS, L. G., NORDBERG MANUFACTURING CO. *U.S. Pat.* 2540358, 1951. The ball mill rotates about a vertical axis, tilting from the horizontal plane as it rotates.

1332. **The Centrifugal Ball-mill Classifier.** WUENSCH, C. E. *Min. Congr. J., Wash.*, 1947, 33 (9), 22–5, 49; *Off. Gaz. U.S. Pat. Off.*, 1949 (3), 766. A vertical ball mill is described, of roughly parabolic cross-section. The bowl revolves at high speed (300–600 rev/min) and fixed ploughs project into the mill and deflect the balls and charge. The centrifugal force increases the grinding rate and causes a classification of the material. Certain defects of this mill are mentioned and methods by which they have been overcome are described. 4 figs.

ROD MILLS

1333. **Plant and Equipment.** ANON. *Chem. and Process Engng*, 1953, **34** (9), 294; *Mine & Quarry Engng*, July 1953, 245. The end discharge rod mill was developed to give a minimum amount of fines. A cubic-shaped particle was produced preferentially. Under dry conditions the centre discharge mill would produce a −4 to −8 product in one pass. The Marcy rod mills (Mine and Smelter Co., U.S.A.) will now be made by a British firm. Three types are made: (1) open-end mills for wet or dry grinding; (2) end peripheral discharge mills; (3) centre peripheral discharge.

1334. **Ni-Hard Aids Rod Mill to Make Excellent Service Record.** ANON. *Nickel Topics*, 1952, **5** (7), 5. The rod mill has replaced rolls for lead and zinc sulphide ores in the Sullivan concentrator of the Consolidated Mining and Smelting Co., Canada. The rod mill, while taking the same raw ore, crushes to a size suitable for feeding to the primary ball mills. The normal rod load is 76 tons or 45% of the total mill volume. The mill is driven at 19 rev/min by a 1000-h.p. motor giving an output of 400 tons per hour. Estimated life 7 million tons of ore.

1335. **Exploitation of Low Grade Ores in U.S.A.** *O.E.E.C. Technical Assistance Mission*, No. 228, 1954. *O.E.E.C., Paris*. Obtainable from H.M. Stationery Office. Chap. IV. Stage grinding, with rod mills in open circuit in the first stage and ball mills in closed circuit with classifiers in the second stage, is becoming the generally accepted practice, although a few of the newly-erected plants still keep to the old practice of 'one easy step'. The last-named practice of one-stage grinding using grate mills working in closed circuit with classifiers, seems, however, to be limited to ores of high grindability. Tests performed at Babbit have shown that rod mills should operate between 55–60% of critical speed, overflow ball mills between 60–65% and grate ball mills at 70% of critical speed for best economical result. As grinding media the usual practice is to use 3-in. rods in the rod mill and 1–2 in. balls in the following ball mill. In single-stage grinding, 3-in. balls have to be used for the largest particles.

1336. **How to Predict Rod Mill Power Requirements.** ARBITER, N. *Engng Min. J.*, 1955, **156** (3a), 63–5. The method is one of dimensional analysis. Performance is predicted entirely from operating data without recourse to theory. The dimensionless groups used were: fraction critical speed, load fraction (i.e. fraction of mill vol. occupied by rods) and a power factor. A table presents these groups together with the mill dimensions of 38 installations, and the resulting power predictions. Model mills were used to establish the relations. 5 refs. The data in the table were taken largely from various authors including Taggart. [P]

1337. **The Rod Mill in the Sullivan Flow.** BANKS, W. R. *Canad. Min. metall. Bull.*, July 1952, **45** (488), 397–403. The author describes the advantages gained by replacing the roll mills for galena with rod mills, both with regard to performance and main-

tenance. Performance data are given, 'Interpretation of the Sullivan Mill in Comminution'. Myers, J. F., *ibid.*, Oct. 1952, pp. 579–82. This contribution describes with diagrams the mechanism of crushing by the rods, i.e. the material becomes finer as it travels the length of the mill. [P]

1338. **Selecting Rods of Proper Size for the Rod Mill.** BOND, F. C. *Engng Min. J.*, 1950, **151** (10), 85. Selection of rods of proper diameter has been a matter of judgment. The paper is an attempt to derive an empirical equation which would represent present practice. The data in deriving the equation is published by Myers, Michaelson and Bond, 'Rod Milling—Plant and Laboratory Data'. *Trans. Amer. Inst. min. (metall.) Engrs*, 1949, **183**, 299. Bond, F. C., Standard Grindability Tests Tabulated, *ibid.*, 313.

1339. **Trends in Grinding.** CRABTREE, E. H. *Min. Engng, N.Y.*, 1953, **5** (2), 158. The advantages of using rod mills to replace fine crushers are described. Although outputs are about the same, the rod mill does the work in open circuit and does it wet, thus avoiding the cost of elevators, screens and chert. The same considerations would apply to dry crushing rolls v. rod mills.

1340. **Latest Development in Fine Grinding.** GLOCKMEIER, G. *Metall. u. Erz*, 1922, **19**, 285. After a discussion of successive types of tube mills, the article closes with a short account of the rod mill, or Marathon mill, in which balls are replaced by steel rods. Illustrations.

1341. **Rod Mill at Sullivan Plant of Consolidated Mining Smelting Co., Canada, Ltd.** (p. 160). KINGSTON, G. J. *Trans. Canad. Min. Inst. (Inst. Min. Metall.)*, 1950, **53**, 152. Hardinge Rod Mill is for fine crushing or coarse grinding. 11½ × 12 ft liners—46 tons, rod load 85 tons, total 171 tons. 1000 h.p. motor, speed 57–74% critical, i.e. 13·5–17·3 rev/min. The wear of the smooth-faced liners is 0·03 lb/ton feed. Feed 7000 tons per 24 hours, from 3% on ¾ inch to 63% on 6 mesh. Rod wear 0·2–0·33 lb/ton. Rod charge 1½–3⅝ in. diameter. Effect of speed on capacity is from 14·1 rev/min at 6670 tons per day to 17·4 rev/min at 8300 tons per day. [P]

1342. **Rod Milling at Snow Lake.** MACDERMID, B. G. *Canad. Min. metall. Bull.*, Sept. 1953, **46** (497), 535–46. After jaw crushing underground and cone crushing on surface, the abrasive ore for flotation cyanide process was ground in two 8 × 12-ft rod mills, commencing in 1949. The performance data are presented in five tables, and liner service record in three tables. The rate of shell liner wear and rod wear is dealt with in detail for each rod mill. Discussions. [P]

1343. **Fine Crushing with a Rod Mill at the Tennessee Copper Co.** MYERS, J. F. and LEWIS, F. M. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 2041, 13 pp.; *Min. Tech.*, 1946, **10** (4). The operation of a rod mill for the fine crushing of ore (about ¾ in. diameter) to give a size of about 20 mesh suitable for subsequent fine-grinding operations is described. The mill functions best in open circuit and the discharge product is controlled by the screening action of the rod mass. Rods of 2½ in. diameter give more new units of surface per horsepower than are produced when using rods 3 in. in diameter. Crushing efficiency is reduced by the presence of rod scrap; more output is obtained by increasing the discharge opening.

1344. **Rod Milling—Plant and Laboratory Data.** MYERS, J. F., MICHAELSON, S. D. and BOND, F. C. *Trans. Amer. Inst. min. (metall.) Engrs*, 1949, **183**, 299; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 2175; *Min. Tech.*, 1947, **11** (4). Rod mills are more efficient when grinding harder ores; that is, ores with high impact crushing strengths, low grindabilities, and high surface energies. Installations that are more efficient in grinding to pass a certain mesh size (product size efficiency) are also generally more efficient in producing new surface. The effects on product size and efficiency of mill diameter, reduction ratio, mill speed and mill volume are discussed, but results of trials are not conclusive. [P]

1345. **Defining the Scope of the Open Circuit Rod-Mill in Comminution.** MYERS, J. F. Symposium on Mineral Dressing, London, Sept. 1952, Paper No. 9. Institution of Mining and Metallurgy. A summary of the author's theory, 1946, as to how the rod mill performs its work. Quotes the opinions of Stevens and Banks and Crocker and summarizes the available information. There is practically no information as to rate of feed v. efficiency. Diagrams of rod relationships. Vertical v. conical end liners. Allis Chalmers find that vertical are 2% more efficient. Criticizes manufacturer's design, and comments on the lack of data to support certain features of design. Advocates the truncated cone for fine grinding. States that the rod mill does its part of comminution much faster than any closed circuited ball mill. Concludes that the fast passage of ore through the rod mill offers a wide field of study in the preparation of flotation feed. Quotes J. T. Stevens, *Hardinge Bull.*, No. 25c, Supt., Kennecot Copper Co., Hayden. Ariz.; H. R. Banks, of Consol. Mining and Smelting Co., B.C., Canada; B. S. Crocker of Lake Shore Mines, Kirkland Lake, Ont., Canada. Dyer, 'Ball Paths in Tube Mills', published in *Recent Developments in Mineral Dressing*. Institution of Mining and Metallurgy, 1953.

1346. **Rod Mill Brings Sand Production into Balance.** NORDBERG, B. *Rock Prod.*, 1953, **56** (10), 101–4. The Dixie Sand and Gravel Corporation has an auxiliary rod mill installation to produce fine sand from surplus pea gravel. Hammer mills were first tried but the maintenance expense was too large. Crushing rolls cracked the gravel but did not produce fines. The mill is an Allis Chalmers double end feed, 4 × 10 ft.

1347. **Photographic Record of Rod Mill Charges.** PENROSE, E. K. *Chem. Engng Min. Rev.*, Jan. 1954, **46**, 143–4.

1348. **Progress Report on Rod Milling at King Island Scheelite, Ltd.** SALAMY, S. G. *Proc. Aust. Inst. Min. Engrs*, 1955 (175), 43–55. The performance of a 6 × 6-ft grate discharge ball mill which was converted to a grate discharge rod mill, with the sole object of obtaining a greater capacity, and to the end of reducing the quantity of −200-mesh scheelite in the product. A combination of primary rod mill and secondary ball mill produced a much improved product as compared with one-stage ball milling. It is hoped that by arranging high-lift rod action, the preliminary roll mill may possibly be removed from the circuit. [P]

1349. **Short-Rod Grinding in Ball Mills.** STARKE, H. R. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 119–22; *Tech. Publ. Amer. Inst. Engrs*, No. 1821; *Min. Tech.*, 1945, **9** (3). Details are given of the results obtained by a change-over from ball to rod mill grinding in the concentration plants of the St. Joseph Lead Co., Missouri, dealing with ore consisting of galena in dolomitic limestone. An increase in power consumption, due to increased weight per unit volume of rods as compared with balls, and leading to finer grinding, was allowed for by decreasing the rev/min. Low-density feed direct to the mills was also introduced so that less grinding would be done on the finer particles and a pipe feeder device substituted for the original cast-iron scoop feeder. The rod consumption was found to be 0·116 lb/ton of ore milled as against 0·168 lb/ton using ball mill grinding. A more uniform particle size was also achieved.

1350. **Developments in Milling Practice.** STOCKETT, N. A. *Min. Congr. J., Wash.*, 1953, **39** (4), 84–5. Wet grinding rod mills replace dry crushing rolls. Construction and advantages are briefly described.

1351. **Effects of Rod Mill Feed Size Reduction.** STROHL, J. J. and SCHWELLENBACH, H. J. *Min. Engng, N.Y.*, 1950, **2**; 1951, **3**; *Trans. Amer. Inst. min. (metall.) Engrs*, 1950, **187**, 1273; 1951, **190**, 1220. The paper relates the results obtained by decreasing the size of feed to a rod mill screen circuit. As would be expected, added production was gained and a finer grind with no tonnage loss was made possible. 1 fig., 2 tables.

1352. **Rod Mill Practice at Ray Mines Division Kennecott Copper Corpn.** TUCK, F. J.

Trans. Amer. Inst. min. (metall.) Engrs, 1939, **134**, 327–9; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 994. Data on performance and costs are given. [P]

RING ROLL MILLS: RAYMOND MILLS

1353. **Runners.** ANON. *Brit. Clayw.*, 1943, **52**, 49. The use of runners fitted with renewable rims avoids expense. The rim can be of any desired metal, mild steel is often used, though some of the tougher alloys are more resistant to abrasion and far more durable. The most suitable shape for the rings must be determined by trial. When a ring is badly worn it can easily be taken off, reversed and replaced; this can be repeated until the ring is so thin that its further use is dangerous. It may then be removed from the machines, placed in a lathe and turned to any suitable dimension.

1354. **The Raymond Bowl Mill.** ANON. *Colliery Guard.*, 28 July 1949, **179**, 116–7. A brief description of design and operation of the Raymond bowl mill as manufactured by Clarke, Chapman & Co., Ltd., Great Britain. Illustrations.

1355. **Plant for Pulverizing Coal.** *Edg. Allen News*, 1955, **34** (393), 57–8; (396), 127. Description of the British 'Rema' ring roll mill. The top roller is mounted on the main driving shaft. This roller drives the vertically-set ring by friction and the latter in turn drives the two lower rollers, whose pressure is maintained by springs. The whole movement can be lifted out of the housing. The life of the 'Cromax' chromium steel with coal is from 2000 to 18 000 hours without replacement of members, depending on the size of the mill. Illustrated.

1356. **Griffin Mills for Grinding Cement and Other Materials.** ANON. *Quarry*, Jan. 1914, **19** (217), 11–15. Illustration and description of the Griffin 30-in. ring roller mill. This consisted of a pan with single roller suspended from a swinging vertical shaft.

1357. **How to Hard Surface Your Coal Crusher Rings.** ANON. *Power*, Feb. 1955, **99**, 148. Rings of S.A.E. 105 steel can be given a highly resistant wear coating by automatic arc welding. Beads are continuous, the surface is dense, and needs no machining. Applicable to e.g. the ring of a Raymond Mill.

1358. **Pulverizing Apparatus.** COMBUSTION ENGINEERING INC., *Brit. Pat.* 612725, 1944/48. Modifications for maintaining controlled air flow and improved separation of ground material in the Raymond bowl mill, by avoidance of zones of high and low air velocity.

1359. **Pulverizing and Separating Machine.** FRASER, G. H. *U.S. Pat.* 2188346, 1932. A ring and rolls type of crusher provided with air separation is described. The largest oversize is returned by an external elevator.

1360. **Very Fine Grinding by the Raymond Roller Mill to 300 mesh; Dustless and with Controllable Size.** INTERNATIONAL COMBUSTION, LTD. *Industr. Chem. Mfr.*, Oct. 1934, Feb. 1936, 17. *See* Publication. G.481, International Combustion, Ltd., p. 16, gives performance data for six materials.

1361. **Apparatus for Reducing the Particle Size of Materials.** MESSINGER, W. *Brit. Pat.* 666200, 1949/52. The apparatus comprises a stationary vertical member with inner grinding surface, a plurality of conical rollers in grinding relation to the grinding surface and supported against downward movement with respect to it; a central rotatable, inverted, conical member engaging and supported by the rollers presses them outwards against the grinding surface.

1362. **Mill Drying.** ROSIN, P., RAMMLER, E. *Ber. Reichskohlenrates*, No. 10; *Braunkohle*, 1927, **27**, 261, 286. Ring roll mill performance on coal with simultaneous drying and grinding. Heat requirements and the necessary compromise between grinding and drying are dealt with.

1363. **A Textbook of Ore Dressing.** TRUSCOTT, S. J. 1923, Macmillan & Co., Ltd., London. In Chap. 3 are illustrated descriptions of Huntington and Griffin ring mills with a single roller mounted on swinging shaft.

LOPULCO (LOESCHE) MILLS

1364. **Improved Roll Mill.** ANON. *Chem. Engng News*, 30th Jan. 1956, **34** (5), 506–7. A modification of the Loesche mill is described wherein pneumatic control replaces spring control of the roll pressure, and improvements are made in the product removal and return design. (Hardinge Co.)

1365. **The Lopulco Mill.** INTERNATIONAL COMBUSTION, LTD., Publication, G.493. A medium-speed machine grinding to fine limits between heavy inclined conical rolls revolving through frictional contact with a rotating table. Illustrated descriptions.

1366. **The Loesche Mill.** LOESCHE, E. C. *Arch. Wärmew.*, 1941, **22**, 241–5. An illustrated description of the development of the Loesche mill for grinding coal, rock and other materials, together with discussions on classification control, pressure, air, screening, output and power consumption and some operational data, presented in tabular form. [P]

1367. **Operational Experience with Loesche Coal Mills.** TEN BRINK. *Mitteilungen Vereinigung Grosskesselbesitzer*, 1951, (4), 288–93. Those mills for pulverization of bituminous coal are distinguished by their low running and repair costs. Running periods exceeding 10 000 hours have been achieved since the introduction of manganese steels and exhauster fan blades of cast chromium steel.

BALL AND RING MILLS: E. TYPE

1368. **Grinding of Minerals in Germany (1939–1945).** *B.I.O.S. Report*, No. 1356, Appendix 17, 1948, H.M. Stationery Office. The Peters Mühle, Model E. Drawings and table of dimensions for various sizes of the Peters vertical ball mill.

1369. **Improvements in Pulverizers.** BABCOCK AND WILCOX, LTD. *Brit. Pat.* 646686, 1947/50. A method is described for securing a resilient but firmly anchored upper ring for applying pressure to the balls in a ring and ball mill.

1370. **Pulverizers.** BABCOCK AND WILCOX, LTD. *Brit. Pat.* 687026, 1949. The upper grinding ring of the ball and ring type mill is given a special form which facilitates the return of oversize particles to the grinding zone and reduces the tendency towards the formation of an annular, relatively dense mass of suspended oversize particles of pulverized material around the grinding zone. *See also* B. & W. publication F.907A, describing the E-type mill.

1371. **Grinding Mills.** COOPER, C. J. *Brit. Pat.* 573296, 1944. Hemispherical grinding elements are supported by vertical spindles, and rotate in the annular trough-shaped bottom of a rotating pan. Stirrer and mechanically controlled outflow are provided.

1372. **Self Classifying Ball Mill.** DRYER, J. H. *U.S. Pat.* 2432610, 1944. Balls of different sizes are disposed in grooves between a series of horizontal discs, fixed and rotatable. Crushed ore is fed downwards through a hollow shaft and distributed upwards into the mill by a stream of water. The size of ball decreases upwards and pressure is controlled by springs above the chamber. Four layers of balls (5 plates alternately fixed) are shown. The mill is of doubtful value.

1373. **Pulverizer Mill.** LYNCH, E. E. *U.S. Pat.* 2318175, 1941. A few large balls are placed in a bowl having a vertical axis, the bowl and a 'floating head' being driven in opposite directions. The balls rotate between these members, the 'floating head' being under spring pressure.

1374. **Mechanical Manufacture of Hollow Bricks.** PROKS, O. *Stavivo*, 1931, 195.

Ball mills are described, which have two crushing tracks arranged one beside the other, differential rollers, and multi-stage presses with automatic feeding devices.

1375. **Grinding Tests on a Fuller-Peters-Mill.** WINTER, H. and FLAMM, A. *Brennst.-Wärmekr.*, Feb. 1953, **5**, 45–9, 76–9. Studies of the influence of a number of variables on the throughput of a ball mill are reported for various Continental and American coals, cokes and breeze. Air separation and classification were employed. Whilst the energy demand on the mill remained uniform, the throughput fell from 7·9 tonnes/hour for coals to 1·8 tonnes/hour for the hardest (American) breeze. Size distributions are given. 10 graphical representations of results, and 3 tables. [P]

BALL AND CONE MILL

1376. **Exploratory Investigations of a Small Laboratory Cone Mill.** BROADBENT, S. R. and CALLCOTT, T. G. *Inform. Circ. Brit. Coal Util. Res. Ass.*, 144, Nov. 1955. Balls rest on a rotating cone and are held by a horizontal retaining ring. A proportion of the coal feed is broken between the balls and cone. The amount of breakage is proportional to the rate of rotation of the cone, and depends on the type of coal and rate of feed. Several mills are described, and the results of exploratory experiments are given. The experiments indicate that at optimum conditions a cone mill would have a high capacity and effect considerable size reduction.

1377. **Coal Breakage Processes. IV.** BROADBENT, S. R., CALLCOTT, T. G. *J. Inst. Fuel*, Jan. 1957, **30** (192), 18–21. A preliminary investigation of the ball and cone mill is reported. The laboratory mill has a track diameter of 4 in. and can produce about 170 lb of -100-mesh coal per hour from a $-\frac{1}{2}$-in. feed. The Pilot mill has a track diameter of 14 in. and produces 4 tons per hour. The effects on performance have been investigated by matrix methods. The two important aspects were (1) the proportion broken (the selection function) and (2) the severity of breakage (the breakage function). For other papers on matrix analysis in coal breakage, *see under* Coal *and under* Open v. Closed Circuit Grinding, the same authors.

PAN MILLS

1378. **Dried Screen Tailings in Dry Pan Aid Grinding of Wet Shale.** ANON. *Brick Clay Rec.*, 1938, **93** (3), 10. Since the shale at the Roanoke-Webster Brick Co. Roanoke, Va., retains moisture for long periods, it is ground in a dry pan, then conveyed to electrically-vibrated screens, the tailings from which are passed through a rotary dryer, returned, and fed, with the shale, into the dry pan, to facilitate grinding. The screening, pugging, and de-airing, especially the production of rough-textured brick, are also described briefly.

1379. **Hard Facing Brick Machinery Parts Cuts Costs of Repairs and Shutdowns.** ANON. *Brick Clay Rec.*, 1947, **110** (2), 54. The economy of using a hard-faced plough in an edge-runner mill is noted.

1380. **A Note on Pan Grids.** ANON. *Brit. Clayw.*, 1942, **51**, 21. A short discussion on the wear of pan grids and advice on how to enable them to carry on longer without replacements. In wet weather, sludgy clay may be forced through grid apertures but is much more difficult through circular apertures.

1381. **Dry Grinding with Edge-Runner Mills.** ANON. *Brit. Clayw.*, **54**, 1945, 104. Means of avoiding the overloading of the edge-runner mill are noted. A preliminary crusher should be used if the material to be ground is more than 2 in. in diameter. Manganese steel has proved to be the most suitable material for the pan bed as it hardens in use and does not become softer with wear. Manganese steel is also used for the steel tyres or rims on the runners; as well as for the gearing and crown wheel for driving the mill. Steam power is mostly used to drive the mill as it is more capable of

withstanding the variation of stress than is power supplied by gas, oil or electric engine.

1382. **On Pan Outputs.** ANON. *Brit. Clayw.*, 1946, **55**, 53. Brief notes on methods of increasing the efficiency of grinding pans are given, including the suggestion of a proportion of dry return, and also efficient scraping to avoid blockage. A covered store for about one week's capacity is recommended for ensuring continued production in wet weather. Flat-faced rollers with hard-alloy parallel ribs increase the efficiency of both rolling and rubbing actions. Hammer-mill grinding of tailing, and 'tandem' screening are also suggested.

1383. **Pity the Perforated Pan.** ANON. *Brit. Clayw.*, 1951, **59**, 302–3, 312. Factors governing the efficient working and economy of perforated pan mills. Feeding into the pan, cleaning down, footstep bearing, lubrication, wear and the necessity of adequate inspection are discussed. Detailed suggestions are given for early avoidance of faults.

1384. **New Designs for Brick Making Machinery.** *Progressus*, 1953, **5** (E3), 17–9. A description of the Karl Handle and Sons Crushing mill and of the Weserhutte Otto Wolff G.m.b.H. edge-runner mill for wet grinding.

1385. **Edge Runners for Dinas and Other Silica Bricks.** ANON. *TonindustrZtg*, 1918, **42**, 693, 706, 722. An illustrated account of edge-runner mills used in the preparation of the siliceous material, some with the motive power applied below and some above.

1386. **Notes on Edge Mills.** ANON. *TonindustrZtg*, 1920, **44**, 488. The runners should preferably be supported by two independent crank axles so as to ensure equal distribution of pressure. Runners supported on a single axle wear more rapidly at the outer end. The perforations in the grate should take the form of long slits running crosswise.

1387. **Edge Runner Mills with High Efficiency and Safety.** ANON. *Ziegelindustrie*, 1951, **4**, 287. Recent improvements in edge mill constructions are discussed in general terms.

1388. **The Preparation of Ceramic Raw Materials. VIII.** AVENHAUS, W. *Ziegelindustrie*, 1950, **3**, 415; 1951, **4**, 1215. The design of various types of edge-runner mill is discussed (i.e. dimensions and wt. of runners, power consumption, specific output, etc.). The method of calculating the specific output is explained by an example. 3 figs, 1 table.

1389. **Metal Wear in the Refractories Industry.** BALES, C. E. *Tech. Bull. Amer. Refract. Inst.*, No. 36, Mar. 1933. Manganese steels are more economical than white iron in grinding plates for dry pans. A special chromium molybdenum steel used for muller tyres considerably outlasted ordinary white iron.

1390. **Screening Efficiency of a Dry-Pan Grinding System.** BROWN, D. P. and HESS, R. *J. Amer. ceram. Soc.*, 1946, **29**, 147. The efficiency of an industrial dry-pan grinding and screening system was measured by making screen analyses of the feed to the screens, the product passing the screens, and the tailings. From these analyses, evaluations of the screening operation and the effect of the dry-pan grind on the screen efficiency were made according to published formulae. The effect of several operating variables in grinding and screening has been investigated and discussed. The factors include percentage recovery v. screen size, clay hardness, the effect of screen plate size, the wear of pan parts and the effect of a new screen installation.

1391. **Chert Stones for Pan Grinding Mills.** DAY-KIRKBY, W., SALT, R. S. and PROCTOR, G. P. *Crush. & Grind.*, 1932, **1**, 107. A brief account is given of the ordinary pan mill used for grinding pottery materials with particular reference to the nature and requirements of 'runners' and 'pavors'.

1392. **Notes on Dry-Pan and Wet-Pan Operations.** GALLAHER, J. M. *J. Amer. ceram. Soc.*, 1929, **12** (5 part 1), 347–50. With given raw materials production costs are

governed by production capacity, plant efficiency and labour. Of importance in this connexion is the pan equipment used. The author discusses (1) recent improvement in design of dry and wet pans, (2) engineering cost data in relation to economical operating speeds, (3) relation of rotation rate to capacity, taking into consideration its effect on emptying device efficiency, (4) the best size for economical operation at various capacities, and (5) the best size of pan for grinding various types of clays.

1393. **Latest Developments in Fine Grinding.** GLOCKMEIER, G. *Metall. u Erz.*, 1922, **19**, 285. The principle of the tube mill with shortened versions is described. The article closes with a short account of the rod mill or Marathon Mill, in which the balls are replaced with steel rods.

1394. **Crushing, Grinding and Pulverizing Equipment for the Refractories Industry.** GREAVES-WALKER, A. F. *Tech. Bull. Amer. Refract. Inst.*, No. 64, Jan. 1937, 12 pp. Classifies the dry pan as a crushing, grinding and impact machine operating by the combined action of pressure, abrasion and impact. States that the capacity of a dry pan is determined largely by the width and design of the slots in the screen plates. Narrow slots for a particular size have been almost wholly replaced by wider slots which allow feed to discharge after one revolution. Cushioning is thus prevented.

1395. **Control and Segregation in Dry Grinding.** HENDRYX, D. B. *Brick Clay Rec.*, 1954 (1), 46. Includes a detailed comparison between the merits of hammer and pan mills in the heavy clay industry. *See under* Ceramics.

1396. **The Development and Importance of the Wet Edge-Runner Mill in the Brick Industry.** HERBRING, W. *TonindustrZtg*, 1943, **67**, 74. An illustrated account is given of the development of the wet edge-runner mill. The first useful type of mill described has a revolving pan and rotating rollers and the drive coming from below; variations of this include a mill with a stationary pan and revolving rollers and a mill with a stationary pan, revolving rollers and an overhead drive. A double track edge-runner mill is also described and one known as the 'Erfurth' system, which was patented in Germany and has a revolving pan and rollers of different diameter and width which are driven by a chain drive so that there is a differential velocity between the pan and the rollers. Again with the 'Konoid' edge-runner mill, the rollers have different diameters and the material is drawn inside by means of a suitably arranged scraper. The step edge-runner mill and the two-storey edge-runner mill are noted. A mill with a feeding combined with a mixing device and a mill with a specific arrangement of the rollers, i.e. one roller travels round the outside of the pan and the other roller travels round the inside of the pan, are described. The latest edge-runner mill is one with direct electrical drive.

1397. **Screens and Gratings for Edge Mills.** HERSEMANN, C. *TonindustrZtg*, 1951, **75**, 80. Suggestions are made for construction details and operation of perforated bottom edge-runner mills. It discusses the effects of the shape (slit or circular) of the grid perforations and of the size and direction of slit perforations. The size, area and relation of the grid to the runners are also discussed.

1398. **Ten-Foot Grinder with Sloping Screen Plate.** INTERNATIONAL CLAY MANUFACTURING Co., Dayton, Ohio. *Brick Clay Rec.*, June 1952, **120**, 58–9. Screening is more efficient and permits higher rotational speeds, since the slope of the screen plates modifies the throw of the material towards the edge.

1399. **Applications of Unit Operations and Processes in the Ceramic Industries.** KOEHLER, W. A. *Trans. Amer. Inst. chem. Engrs*, 1944, **40**, 575–92; *Ceramic Abstr.*, 1945, **24**, 76. A new development in dry pans is the use of lightweight mullers in combination with air cylinders, thus providing a variable pressure range of 3–9 tons.

1400. **The Edge Runner Mill.** LOCKE, K. *Silikat Technik*, 1952, **3**, 152. Construction and efficiency are discussed.

1401. **Improvements Relating to Edge Runner Mills.** Loesche, E. G. *Brit. Pat.* 680776, 1949/52. A modification in the supports of the runners which alters the disposition of the runner to the edge ring and diminishes wear and makes it uniform.

1402. **Grinding Mills of the Edge Runner Type.** London Brick Co., Ltd., Hersee, E. D. *Brit. Pat.* 699848, 1953. The amount of material in the pan is mechanically controlled through feed control by means of a rod lifted or lowered by the mullers.

1403. **A Study on Pan Grinding.** Mellor, J. W. *Trans. ceram. Soc.*, 1930, **29**, 271–9. A quantitative investigation into the effects of variables in pan mill grinding. It is concluded there is no appreciable fundamental knowledge to support the conditions usually found in operation, and that investigation is necessary into relations between speeds and efficiency, area of grinding surface and capacity of pan, and certain other variables. In this paper the analysis of a double edge-runner mill is presented with reference to geometrical and speed characteristics.

1404. **Roller and Ring Pulverizer of the Edge Runner Type.** P.H.I. Engineering, Ltd. *Brit. Pat.* 672009, 1950/52. The pulverizer consists of a rotating grinding table and stationary thrust ring above, with grinding rollers rotating under spring pressure between them, the spring bearing on to the thrust ring which is shaped to bear on the roller neck. The guiding rollers have pins at both ends, located in rotating guide rings so that they move only in a plane vertical to the grinding table.

1405. **Improved Method of Oiling the Mullers of Edge Runner Mills.** Pristupa, P. G. *Fireproof Mat., Moscow* (*Ogneupory*), 1949, **14**, 364; 1950, **15**, 1510. The hubs and flanges of mullers became more stable and did not have to be replaced so often when the oiling system was changed. The improvement is described. 2 figs.

1406. **Development in Dry Pan Construction.** Reed, P. B. *Brick Clay Rec.*, 1924, **65** (5), 322; *Ceramic Abstr.*, 1924, **3**, 353. The rate of output of a dry pan depends much more upon the design and location of the mullers than upon the screen plate area. An older type of 9-ft pan had 12 × 54-in. mullers, each having a weight of 7429 lb. The width of the screen plates was 18 in. and the grinding area in one revolution was 3419 sq. in. The diameter of the newer type of pan was reduced from 9 ft to 8 ft 6 in. by taking 3 in. off the outside of the screen plates. The mullers were moved out 3 in. thus taking 2 in. off the inside of the screen plates. The dimensions of the mullers were $14\frac{1}{2} \times 55$ in. each having a weight of 9301 lb. The width of the screen plates was 12 in. and the grinding area in one revolution was 5938 sq. in. It was also found that wider slots in the screen plates produced more fines. The $\frac{1}{16}$-in. perforations were replaced with openings from $\frac{1}{4}$ to $\frac{1}{2}$ in. and even larger, the limit being when too great a load is placed on the elevator and screen due to too large a percentage of tailings being returned to the pan. By selecting the correct screen openings the new 8 ft 6 in. pan will grind from 40 to 50 tons of 12- to 14-mesh hard fireclay dust per hour.

1407. **Edge Runner Mills in the Ceramic Industry.** Reich, H. *Keramische Zeitschrift*, 1952, **4**, 362–5. The action of an edge-runner pan mill upon the grains of material in clay minerals is explained. The large grains or agglomerates are broken down but the smaller particles are abraded. In addition there is a shearing action which results in the coating of the grains with thin films of water, thus improving the workability of the clay, a conclusion which justifies the reliance which has long been placed on the edge-runner mill. The action of the runners is illustrated diagrammatically with geometrical analysis.

1408. **Automatic Operation of Mixing Edge Runners.** Repnikov, V. A. *Fireproof Mat., Moscow* (*Ogneupory*), 1951, 444; 1952, 1140. Automatic control for mixing batches of grog and clay for blast furnace bricks is described in detail. 3 figs.

1409. **Dry Pan Investigations Using Small Sample Technique.** Richards, R. *Trans. Brit. Ceram. Soc.*, June 1955, **54** (6), 367–87. *See under* Ceramics. [P]

1410. **What is the Proper Speed for Dry Pans.** SEANOR, J. *Brick Clay Rec.*, 1954, **124** (1), 45; (2), 55, 83. The 'angle of nip' is one of the most important factors in the performance of a pan mill: factors affecting this angle are fully discussed. As a rough guide, pan speeds vary with the size of the feed as follows: lumps up to 6 in.—24 to 26 rev/min, 3 in. and smaller—32 to 36 rev/min, $1\frac{1}{2}$ in. and smaller—36 to 40 rev/min, $\frac{1}{2}$ in. and less—over 40 rev/min. Effective angle of nip is reduced as speed is increased.

1411. **Practical Merits and Theoretical Values in the Preparation of Clay.** SPINGLER, K. *TonindustrZtg*, 1942, **66**, 403. An account is given of apparatus used for the wet and dry preparation of clay. Output of bricks per hour for a single wet edge-runner mill ranges from 1000 at 5 h.p. to 4000 at 25 h.p. Output for a double wet edge-runner mill per hour ranges from 1500 at 10 h.p. to 7000 at 40 h.p. Output for a double-stages wet edge-runner mill per hour ranges from 3000 at 25 h.p. to 7000 at 40 h.p. A standardization and simplification of the apparatus is suggested. [P]

1412. **Developments in Clayworking Machinery.** SYKES, L. J. *Trans. Brit. Ceram. Soc.*, 1939, **38**, 378. The design of edge-runners is discussed.

1413. **The Size Distribution of Broken Solids.** TAYLOR, J. *J. Inst. Fuel.* 1953, **26** (9), 133–8. This paper includes a discussion of a ground product of maximum packing density. It is not easy by crushing alone, i.e. without sieving and remixing, to obtain a high packing density. This may explain the continued popularity of the solid bottom pan mill in the refractory industry, despite its low mechanical efficiency. *See under* Size Distribution. *See* No. 405.

GRINDING ROLLS

1414. **Grinding Rolls.** *See also under* Paint.

1415. **Preparing the Surfaces of Grinding Mill Rolls.** BUHLER, GEBR. *U.S. Pat.* 2518836, 1950; *Off. Gaz. U.S. Pat. Off.*, 1950, **637** (3), 826. A device for preparing the surface of newly manufactured or trued mill rolls is described.

1416. **Improvements Relating to Roller Mills.** BUHLER, GEBR. *Brit. Pat.* 646540, 1948/50. A resiliently mounted delivery plate is described for the exit from a roller mill to divide the stream of crushed material. It is mounted symmetrically at the exit from the roller nip in order to break up flakes.

1417. **Improvements Relating to a Method for Disposing Parallel Adjustable and Fixed Roller Sets or Frames.** BUHLER GEBR. *Brit. Pat.* 720961, 1952/54. The method employs a system of levers.

1418. **Grading of Material.** CAREY, W. F. *Gas J.*, 1940, **231**, 164; *Ceramic Abstr.*, 1943, **22**, 35. He describes a method for giving a high yield of closely-graded material, e.g. between 500 and 100 μ, which depends on producing a ribbon of the over-size grains several grain sizes thick. This ribbon is passed between rolls where its thickness is reduced, e.g. from five particles to four, thus forming fines by rubbing corners off the particles. The system is applicable to brittle materials (coal, granite, and anhydrite) and to soft amorphous materials. A full-scale machine crushed material originally between $\frac{3}{4}$- and $\frac{3}{8}$-in. mesh (19 000 to 9500 μ) to 1675 to 420 with a loss of only 15%. Two precrushing stages were used to ensure small reduction ratios.

1419. **Roll-Mill Grinding: II. Design of the Mill.** DRAPER, C. R. *Paint Manuf.*, 1943, **13**, 42; *Amer. Ceramic Abstr.*, 1948, **31**, 227.

1420. **Roller-Mill Equipment.** GRANT, W. J. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1949 (296), 599–605. An account is given of the development of roller-mills and advice is offered on installation, operation and maintenance.

1421. **Working with Roller Mills.** HANTUSCH, O. *Farbe u. Lack*, 1949, **55** (3), 87–9. A description of the adjustments that can be made to roller mills to secure optimum performance. Illustrated.

1422. **Improvements in Hydraulic Control Mechanism for Roller Grinding and Like Mills.** Holmes Bros., Paint Machinery, Ltd. (London). *Brit. Pat.* 715806, 1950/54.

1423. **A Study of Reduction by Roller Mills.** Khusid, S. D. *C.R. Acad. Sci. U.R.S.S.* (*Dokl. Akad. Nauk., S.S.S.R.*), 1953, **88**, 449–52. (Translated by O.T.S., U.S. Dept. Commerce, Washington, as *Tech. Rep.*, No. 22.) The deformation of particles between serrated rollers and the character of resulting product is studied and illustrated.

1424. **Devices for Use in Connection with Roller Mills.** Miag Muhlenbau und Industrie G.m.b.H., Brunswick. *Brit. Pat.* 718531, 1952/54. An improved device for adjustment and parallel displacement of the loose roll.

1425. **New or Improved Stripper Arrangement for Keeping the Rolls of Roll Mills Clean.** Miag Muhlenbau und Industrie G.m.b.H., Brunswick. *Brit. Pat.* 718670, 1951/54. A comb-like stripper is mounted on the supporting bar so that clamping is firm but adjustable.

1426. **Notes on the Power Used in Crushing Ore with Special Reference to Rolls and Their Behaviour.** Owens, J. S. *Trans. Instn Min. Metall., Lond.*, 1933, **42**, 407; 1935, **44**, 421. After a theoretical treatment of crushing phenomena, the author develops an equation for work done in roll crushing. The conditions of drop test are compared with the setting of roll crushers. Comparison tests are made with roll crushers and drop-weight apparatus. Several types of equation are deduced. [P]

1427. **Investigation of the Method of Operation of Air Classifiers.** Rosin, P. and Rammler, E. *Ber. Reichskohlenrates*, No. 24; *Zement*, 1930, **19**, 984, 1011, 1035, 1060. Performance data are presented from experiments with a three-roll mill with a Pfeiffer air classifier. The effects of throughput, speed and circulating rate on the working of the classifier, and the separating efficiency at different finenesses are given. [P]

1428. **An Arrangement for Adjusting the Rolls of Rolling Mills.** Schlomann, A.G., Düsseldorf. *Brit. Pat.* 706146, 1951/54. The setting spindle is actuated by an additional drive provided by a motor and friction, magnetic or dog-clutch, which permits in conjunction with coupling possibilities, a slow setting and prestressing of the roll bearer as well as a simple release of a roll which is binding.

1429. **Special Applications of Grinding Machines.** Scott, R. A. *Chemical Engineering Practice*, Vol. 3, Chap. 5, pp. 109–27. Butterworths Scientific Publications, 1957. The arrangements and applications of roll crushers, especially fluted roll crushers to the reduction of grain to flour are described and illustrated. Applications of millstones to corn grinding are discussed, attrition mills and hammer mills are also discussed in relation to flour milling and similar reduction. 6 refs.

1430. **The Laws of Grinding with Cylinder Grinders.** Seguiti, T. *Rev. Industr. min.*, July 1952, **33**, 537–46. A summary of earlier work and results of numerous crushing trials on many minerals and rocks are presented. It is found that 50% of product passing the rolls is of larger dimension than the set of the roll gap. From this, and other data, diagrams are constructed from which it is possible to predict the size characteristics of the product from any type of grinding rolls. The work was carried out with commercial equipment with large samples.

1431. **Fine Crushing Rolls as a Mineral Dressing Machine.** Spingler, K. *Ziegelindustrie*, 1950, **3**, 509–11. Its present-day use in the ceramic industry and method of calculation of output and performance are discussed, and useful information on operation and maintenance is presented.

1432. **Grinding and Sifting.** Tubman, F. De M. *Chem. & Ind.* (*Rev.*), 1932, 330–7. A review of roller, hammer, attrition, ball and tube mills, and oscillating, gyrating, and centrifugal sieving machines. The success of roll mills depends on hardness and depth of chill, thickness of roll walls, degree of rapid cooling possible, type of rollshaft, construction and lubrication of gears. The use of gear wheels with double-helical teeth

efficiently lubricated for high-speed roll mills is indicated. The advantages of a new type of one-roll mill, in which the roll is totally enclosed in a casing provided with a grinding block on each side of the casing, for use with paint, etc., are indicated.

1433. **Formula for Calculating the Capacity of a Roll Mill.** YOSHIDA, J. *J. Soc. Rubb. Ind., Japan*, 1948, **21**, 51–3; *Chem. Abstr.*, 1948, **42** (22), 9227. *See under* Paint.

DISC MILLS

1434. **Homax Mill.** *Confect. Prod.*, Mar. 1955, 227–9. A mill for pregrinding or for cocoa nibs or almost any paste which liquefies during milling, including paint. The stones (vertical) can be set to distances up to $\frac{5}{32}$ in. apart. Roller mill fineness is not claimed, but makes an efficient pregrinder for cocoa nibs, which can be reduced to 100–150 micron size.

1435. **Improvements in Grinding Apparatus for Fibrous, Granular and Pulverulent Materials.** ASPLUND, A. J. A. *Brit. Pat.* 706383, 1952/54. Additional support is provided for the horizontal shaft of a disc grinder to enable fine adjustment to be made with a view to being able to arrange the disc peripheries to a hundredth of a mm, which is desirable for very fine comminution of fibres, etc.

1436. **Centrifugal Grinding Mills.** BEUSHAUSEN, W. and RUMPF, H. (ALPINE AG). *U.S. Pat.* 2712416, 1955. Two discs with comminuting members on their faces, mounted on a horizontal axis and rotating at different speeds.

1437. **High Speed Grinding Machines.** BILLON, J. *Peint.-Pigm.-Vern.*, 1951, **27** (3), 170. Describes high-speed grinding mills recently introduced into France from the U.S.A. Grinding is effected by two carborundum stones, one fixed and the other revolving at 3000 rev/min. Fineness of grind is governed by adjustment of the distance between the stones and there is little wear on the stones, which only require renewal every three or four months. Three sizes are described, of capacity 30–60 litres per hour, 1200 litres per hour, and a large production size, respectively.

1438. **Improvements in or Relating to a Wet Grinding Mill.** ELS, H., FRINGS, A. and MEIJNER, M. *Brit. Pat.*, 660954, 1948. A wet grinding disc for mustard and the like has a stationary and revolving millstone, which can be adjusted during operation, and changed without dismantling the mill.

1439. **Morehouse Laboratory Mill.** GUEST INDUSTRIALS, LTD. A mill for laboratory processing and control work. Grinding is done by a carborundum stone revolving at high speed against a stationary carborundum stone, $\frac{3}{4}$ h.p. requirement.

1440. **Stone Disc Grinding Mills with Unitary Material Impeller Secured to Runner Stone.** MACEK, M., Snr. *U.S. Pat.* 2704189, 1952/55. The impeller is a paddle wheel mounted on or in the upper runner.

1441. **Disc Type Disperser of Pigment Suspensions.** RAFTON ENGINEERING CORPORATION. *U.S. Pat.* 2448049, 1948; *Chem. Abstr.*, 1948, **42** (21), 8493h. Solids in liquid suspension, particularly pigments, are dispersed by impact shock against the serrated outer edges of a rapidly rotating disc. Adapted to chalk slurries.

1442. **A Pulverizing Mill for Wood Knots or Wood Pulp.** SAITO, T. *Brit. Pat.* 723270, 1952/55. A coarse crusher or shredder consisting of fluted or similar rolls in a horizontal casing, precedes a disc mill with horizontal shaft and axial feed. The grinding elements are confined to the outer parts of the discs and the gap converges to the edge. The grinding elements are of serrated design.

1443. **Plant for Pulverizing Coal Using a Plate Mill as an Air Entrainment Mill.** STEINKE, E. *Silikat Technik*, 1951, **2** (11), 1000. Coal is reduced to 90% passing a 70-mesh sieve under reduced pressure, and dried by air at 180°C. Power consumption is 28–30 kWh per ton.

1444. **Grinding Mill.** U.S. Fuel Research Corporation. *Brit. Pat.* 592828, 1945. It is claimed that one passage through this disc mill will reduce such material as coal to 100% passing a 325-mesh sieve and 50% below 10 microns. Large sizes can be constructed.

1445. **Improvements in Grinding Discs.** U.S. Fuel Research Corporation. *Brit. Pat.* 643249, 1950. Improvements in colloid mills are described. 100–200-mesh material can be ground with liquid to less than half-micron size without excessive wear of the discs, by virtue of the larger particles being held up in 'closed chambers' in the discs.

MISCELLANEOUS GRINDING MILLS

1446. **New Grinder with 3000 rev/min Knives for the Food and Chemical Industries.** Anon. *Chem. Processing*, 1957, 3 (2), 22. Two sets of knives are mounted on a disc which revolves in front of a perforated plate; by fine adjustment, ultrafine cutting or emulsification can be achieved. Capacity 500–2000 lb/h.

1447. **Fine Grinding Equipment. Some Recent Transatlantic Developments.** Anon. *Chem. Tr. J.*, 27 July 1945, **117**, 106. Three attrition mills are described. (1) The De Anza mill, which is essentially a horizontal bowl revolving at 1200 to 2000 rev/min. The crushed material is dropped into the bowl and reduction is effected by the particles moving against each other. Power costs for equivalent reduction are one-third those for a ball mill, and wear is negligible. The stated capacity is up to 500 tons a day. (2) A 200 ft long closed 2-in. pipe, round which the material, e.g. graphite, moves at about 10 feet/s. (3) A micro-atomizer for the range 1–20 microns, consisting of a rotor with special impact members, a pair of dispersion rings for air dispersion, two separator wheels to reject oversize and two fans.

1448. **The Filmill.** *Chem. Engng*, 1952, **59** (8), 176. The milling is done by a vertically set ring having a wedge-shaped inner periphery, and revolving and grinding between the oblique outer surfaces of two stationary adjustable discs. The feed is forced by a pump at up to 4000 lb/sq. in. through the central shaft of one disc, and this together with centrifugal force, enables the feed to pass through the double gap which can be adjusted from 0·001 to 0·015 in. The other stator can be water cooled. Performance is claimed to be superior to that of conventional roller mills and mixers for stiff pastes or doughs.

1449. **Improvements in or Relating to a Method of, and Apparatus for, Crushing or Grinding Material.** Cross, E. J. (Communication from Nordberg Manufacturing Co.) *Brit. Pat.* 623820, 1946. A grinding mill with flexible side walls has a portion of this wall dented inwards by an outside roller. A material is fed into the revolving mill; it is carried by centrifugal force to the side walls, and as it comes to the portion of the wall that is distorted it is pushed by the bulge against the impact member, and so crushed or ground.

1450. **Improvements in or Relating to Pulverizers.** Cunningham, R. J. *Brit. Pat.* 615652, 1946. Balls are located in the cylindrical bowl at the bottom of a pulverizer, and a stream of fluid carrying the material is injected into the bowl at one or several points and causes the balls to rotate. A central cone in the bottom of the bowl controls the movement of the balls, or if a gas is used a valve controlled outlet in the top of the bowl controls the outflow velocity.

1451. **Improvements in Pulverizing Apparatus.** Foster Wheeler, Ltd. *Brit. Pat.* 696950, 1949/53. The grinder consists of freely-mounted rings as grinding elements on one or more rollers mounted in the pulverizing chamber. The rings move laterally and rotatively to one another. Air classification is provided if desired and the size of feed is not critical.

1452. **Enforced Order Crusher and Mixer.** Frenkel, M. S. *Chem. Age, Lond.*, 29 Oct. 1955, **73** (1894), 947–54. The worm extruder has a continuously conical inter-

face between inner and outer screw, to permit relative axial motion between them. This provides the foundation for developing the mixer into a crusher and provides for easy adjustment. 11 figs., 4 refs. *See also* 1954, 72, 1435.

1453. **A New Type of Diamond Crusher.** FRITSCH, O. *Industr. Diam. Rev.*, 1953, **13**, 207. A coffee mill type mill with a slow moving plain ram does the crushing, and separation into sizes is effected by an elutriation vessel attached to the outlet tube. A ball mill is used to improve the crystal shape where required.

1454. **Apparatus for Grinding and Breaking up Granular or Piece Materials.** GERDEMANN, O. *Brit. Pat.* 720972, 1952/54. A ball of approximately equal diameter to the vertical cylindrical vessel containing it, the vessel being provided with a hemispherical bottom, crushes the material fed from the top of the vessel in the narrowing space between the ball and the vessel outlet at the bottom. The vessel is mounted on springs and is vibrated by the eccentric provided. The ball may be provided with a shaft located in a guide at the top of the vessel.

1455. **Simultaneous Grinding and Flotation.** SCHELLINGER, A. K. and SHEPARD, O. C. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 2461, 1948. A laboratory bowl mill enables flotation to be done simultaneously with grinding, the latter being by balls moving on a perforated base, through which air is forced upwards. *See under* Ores.

1456. **Apparatus and Method to Comminute Solid Particles in Gas.** TANNER, H. G. *U.S. Pat.* 2552603, 1951. *Off. Gaz. U.S. Pat. Off.*, 1951, **646** (3), 778. The method of comminuting finely-divided particles comprises suspension by agitation in a gas under compression, passing through a narrow annular turbulent zone having a width of not greater than $\frac{1}{8}$ in. and being bounded on its outside by a rigid stationary surface and on its inside by a hard, smooth surface, moving at a speed of not less than 100 ft/s. The drawing shows the rotor to have a narrow conical or cylindrical periphery, the whole rotor having a very narrow clearance. The rotor was of the order of 3 in. in diameter. An example is included in the specification of the reduction of penicillin to 4 microns in compressed nitrogen at a rotor speed of 35 000 rev/min. (The patent is a U.S. Govt. monopoly.)

HAMMER MILLS

1457. **Cast Magnesium Rotor Stands High Speeds, Shocks, Stresses.** ANON. *Amer. Foundrym.*, Aug. 1951, **20**, 51–2. *See under* Wheat; Flour.

1458. **Atomill.** ANON. *Ceramics*, 1949, 198; *Trans. Brit. Ceram. Soc.*, 1950, **49** (1), 31. This is a high-speed swing hammer pulverizer, self-contained and self-feeding, and can be used for reducing raw clays from $\frac{1}{2}$ in. to -300 B.S. in capacities up to 40 cwt/h (75–99% passing the screens). The mill is dustless.

1459. **Swing Hammer Mills.** ANON. *Chem. Age, Lond.*, 26 Mar. 1955, 745. A description is given of British Jeffrey Diamond swing hammer mills for the reduction of a large range of materials, including roots, bark, copra, cork, corn cob, fruit peel, paper, peat, straw, town's refuse, wood refuse and tobacco. The mills have been applied as primary units and in multistage milling. The hammer can be used in four positions so as to utilize four wearing edges. Capacities 10–250 tons per hour. Product. 80–90% $-\frac{1}{8}$ in. mesh in one operation.

1460. **Pulverizer Hammer Life Increased by Hard Facing.** ANON. *Chem. Engng and Min. Rev.*, 1953, **45** (6), 220–1. Describes and illustrates the use of a special alloy, cobalide, for facing hammers for fine pulverizing. They prove to be economic in use.

1461. **Chemical Engineering at the British Industries Fair.** *Chem. and Process Engng*, 1953, **34** (5), 143. A description of the 'Intermediate Atomill' especially suitable for the chemical, colour, cosmetics, food and plastics industries where frequent cleaning is a necessity. A 10-h.p. motor drives the shaft on which 10 hammers are mounted which

pulverize the material against heat-treated steel liners. The mill may be used continuously and has 50–60% of the capacity of the larger Atomill.

1462. **Micro-Grinder.** *Chem. and Process Engng*, 1955, **36** (5), 188. A multi-stage hammer mill grinds dyestuffs, limestone, gypsum, cocoa, resins, pharmaceutical products. Capacities from ½ to 5 cwt/h from 1 to 25 microns, i.e. 325 mesh and finer. Machine requires minimum maintenance, little floor space, suitable for rapid cleaning where changes of product are frequent.

1463. **Circular Saw Shock Treatment.** ANON. *Chem. Processing*, 1956, **11** (15), 4–5. The mill consists of a circular saw, 36 in. in diameter, ¼ in. thick with 226 teeth, and revolving at 3600 rev/min using a 125-h.p. motor. 60 nozzles are arranged around the saw and project slurry of the order of 6:10 pigment–water at the advancing teeth, at 80–100 lb/sq. in. About 20 tons of pigment solids per day can be passed through this mill. It is thought that the shock action of the mill compresses the individual clusters, made up of minute crystals of calcium carbonate type pigment so that there is less penetration of the adhesive (paper coating) into the clusters and consequently less wastage.

1464. **Pulverizing Light Materials.** *Edg. Allen News*, 1953, **32** (368), 31–3. Illustrated description of a high-speed multi-hammer mill, suitable for pulverizing light materials, as listed, from wood refuse, shellac to chalk and asbestos.

1465. **Disintegration by Rema.** *Edg. Allen News*, June 1956, **35** (408), 113–5. The Rema range of (hammer) disintegrators is illustrated and described in detail. Rapid access and also air flow are provided.

1466. **Reitz Laboratory Angle Disintegrator.** ANON. *Laboratory Practice*, 1954, **3** (1), 41. The 'angle disintegrator' is claimed to be suitable for laboratory crushing, grinding, pulverizing, pulping, shredding, triturating and defibrizing. It can be adapted for blending, mixing, etc. A surrounding screen allows primary and secondary fractions to be discharged separately. The rotor has a number of arms, each having a hardened broad face or hammer of manganese steel.

1467. **High Speed Laboratory Grinding.** ANON. *J. sci. Instrum., Lond.*, 1952, **29** (6), 206. Quantities from a few grams to several pounds are ground to 300 B.S. in a few minutes in a 5-in. grinding chamber by 12 hardened hammers at 10 000 rev/min and a ½-h.p. motor (shaft mounting).

1468. **Impact Breaking.** ANON. *TonindustrZtg*, April 1953, **77** (7/8), 144–6. A discussion of the mechanism of impact breaking. Expressions are deduced relating the speed and weight of the particles, free path of the particles and other factors.

1469. **Impact Crushing.** ACKERMAN, L. *Min. Mag., Lond.*, Oct. 1953, **89**, 201–12. The results of crushing tests on auriferous quartzites and conglomerates of the Tarkwaian and Witwatersrand series are discussed in terms of current theories of crushing and grinding. The power economy of impact crushing to fine sizes is compared favourably with that of the cylindrical mills commonly used for the final stages. The impact mills were hammer mills and pneumatic pulverizers (with target). Tables of data are given for theoretical and actual surface area, energy input in drop-weight tests, free impacts on Tarkwaian quartzite, comparison of ball mill and impact crusher as concerns size of product, pneumatic pulverizer tests, available power of a pneumatic pulverizer. [P]

1470. **Pulverizing Mills.** BABCOCK AND WILCOX, LTD. *Brit. Pat.* 668775, 1952. Relation to the mechanism of air classification and warm air throughput for a hammer mill on a horizontal axis. The classifying zones are above the mill.

1471. **Operational Experience with Hammer Mills for Brown Coal Firing.** BECHDOLDT, H. *Mitteilungen der Vereinigung der Grosskesselbesitzer*, 1953 (22), 326–8. Experience with two makes is compared, one with tangential and the other with axial air admis-

sion. Wear in the latter was excessive and necessitated reconstruction. Although modified for tangential air admission from below, hammer wear became less but was still greater than that of the first mill. [P]

1472. **Possibilities of Improvement of Hammer Mills.** (In Russian, with Résumé in English, French and German.) BELENI, I. *Acta tech., hung.* (Academy of Science), 1955, **10** (3/4), 355–92. For grain crushing and stock feeding, the most important requirement is the increase of fineness of the finished product. By boosting the peripheral speed, power demand and energy consumption are increased, as shown in tabular form, while fineness of product is increased. Energy demand for producing 1 sq. cm of new surface may be considered as independent of peripheral hammer speed. The specific energy for a product passing a 3-mm screen was found to be 3·6 to $4{\cdot}2\times10^{-7}$ kWh/sq. cm and $2{\cdot}8$–$3{\cdot}2\times10^{-7}$ kWh/sq. cm for barley at 10·8% moisture and maize at 18·0% moisture respectively. For grinding without screening, it was established that though output was high, the fineness of the product did not approach stock farming requirements even at 90 m/s hammer speed.

1473. **Modern Machines for Dry Size Reduction in the Fine Size Range.** BERRY, C. E. *Industr. Engng Chem.* (*Industr.*), 1946, **38** (7), 672–8. Two forms of hammer disintegrator are described and illustrated. These are for fine grinding and are provided with single or double whizzer classifiers. (1) The Microatomizer with 12-in. diameter rotor. (2) The vertical Raymond mill. A performance curve for size separation from 1 to 8 microns against rotor speed is given.

1474. **Carbide Tipped Hammers Cut Pulverizing Costs.** FAWCETT, W. E. *Iron Age*, 27 Nov. 1952, **170**, 114–16. Tungsten carbide tips are claimed to last 100 times as long as normal hammers. Illustrations and uses are presented with examples of improved output.

1475. **Unusual Techniques in Grinding.** FOOTE, J. H. *Chem. Engng Progr.*, 1953, **49** (2), 72. The wider the hammer head the finer the product. For fine grinding it has been found of advantage to have a single piece head supported by several legs. For very soft materials a tapering head having a cutting action has been found advantageous.

1476. **The Use of Hammer Mills in the Glass Industry.** JOBKES, J. *Glastech. Ber.*, 1949, **22**, 407. The recently-developed use of hammer mills, which weigh less and consume less power than other pulverizers, for grinding cullet, limestone, etc., in glass plants is noted, together with average outputs for different types of charge. 1 fig., 1 table. [P]

1477. **Increased Output in Air Swept Hammer Mills.** KROHL, E. *Braunkohle, Wärme und Energie*, 1954, **6** (5/6), 98–102. A description of how modified mechanical features can improve output. Detailed description with illustrations is given of the slotted hammer head and shafts for quick replacement.

1478. **Tertiary Crusher for Soft Home Ores.** LANG, C. *J. Iron St. Inst.*, 1951, **168**, 164. To avoid the build up of fines on the breaker plate (the hammer tips always remaining clean) a double opposed roll should maintain all hammer tips clean.

1479. **The Attritor Pulverizer and Some Typical Application to Furnaces.** MORLAND, A. G. Pulverized Fuel Conference, Institute of Fuel, 1947, 212–16. The previously crushed coal is fed to the pulverizer where it is flung in turbulent motion by impellers and finally removed in an air stream which can also be used as the drying medium.

1480. **Manganese Steel in Crushing Machines.** PICKERING, W. B. *Sands Clays Miner.*, 1935, **2**, 73–80. A new field was opened up to metallurgical practice by the invention of manganese steel, the only steels previously in general use being iron-carbon alloys. Various types of crushers, etc., in which manganese steel is now used are described and illustrated.

1481. **Possibilities and Advantages of Impact Crushers in Ore Dressing.** PUFFE, E.

Z. Erzbergb. Metallhüttenw., 1950 (III), 41–7, 75–7. Prall mills were used for the first time in ore dressing, low-grade lead–zinc ore at Mechernich. They were not merely additional machines, but performed special functions with the ore concerned, and should do so with other materials. The use of prall mills deserves greater attention. The two types of mills used were by Hazemag, Munster. The mills are described and illustrated, the effects of variables are presented graphically and a table is presented to show the advantages of the prall mill in respect of quantity of output, power per ton output and cost per ton output over other breakers and mills, i.e. jaw and roll crushers, hammer mills and ball mills. The greatest differences are between the ball mills and the prall mills, where in all cases for mischerz being ground, the advantages of the prall mill were from 2 to 6 times, 18 and 10 times respectively. The advantages in selective crushing are determined and illustrated quantitatively. [P]

1482. **The Use of Tungsten Carbide in Coal Pulverizers.** ROGERS, W. C. *Mech. Engng, N.Y.*, 1950, **72** (11), 913–14. Description of the use and performance of tungsten-carbide protective facing on pulverizer grinding elements. A new design of mill which takes full advantage of this material is shown. Coals of up to 20% moisture have been pulverized successfully.

1483. **Investigation of an Impact Pulverizer.** ROSIN, P. and RAMMLER, E. *Ber. Reichskohlenrates*, C.55; *Arch. Wärmew.*, 1935, **16**, 13. Performance data for an Anger mill (air jet). Curves are given to show the relationship between output and fineness, kW, kWh/ton, air consumption and velocity, and kWh/ton and fineness. The energy varies from 20–24 kWh/ton. For earlier results see *Braunkohle*, 1934, 449, 467, 481. [P]

1484. **Swing Hammer Mills.** RYDER, P. G. *Edg. Allen News*, June/July 1947. Includes a comparison between costs of swing hammer mills v. other types. The power consumption is of the same order as tube, ball and ring roll mills, but maintenance costs are several times as great, for 85% coal passing B.S.S. 200 and delivering 30% primary air.

1485. **Scott-Rietz Equipment for the Food and Chemical Process Industries.** SCOTT, G. & SON (LONDON), LTD. Bulletin 118, 1954. The Scott-Rietz disintegrator described and illustrated is a hammer mill (with screen) on a *vertical* shaft, ball bearing and bottom discharge. Four ranges from 5 to 400 h.p., 1800 or 3600 rev/min. A Scott-Rietz pre-breaker is illustrated. This is a slow-speed hammer mill with horizontal shaft revolving in a horizontal housing. The latter is fitted with stationary anvils and with deflectors for end discharge. ½–100 h.p., 10–600 rev/min., in a range of five models.

1486. **H.S. Mill: Construction, Application, Performance.** SEIDL, H. *Arch. Wärmew.*, 1942, **23**, 81–5. This air-swept hammer mill by (German) Babcock and Wilcox is developed from the Kramer mill, and its installation is discussed. Operating data show that it is decidedly superior to the Kramer mill. A tabular comparison of performance with that of the Kramer mill and of performance with various brown coals and hard coals is presented. [P]

1487. **Sieveless Hammer Mill for Fine Product.** SULTOR, K. H. *Zement-Kalk-Gips.*, 1953, **6** (1), 25–7. Pneumatic separation is employed with oversize return and final air filter after the bulk of product has been removed by cyclone. Two plants, for large and for small output, are illustrated. Regulation of grain size. 4 refs.

1488. **Impact Mill.** TORLACH, A. *Z. Ver. dtsch. Ing.*, 1955, **97**, 493–6; *J. Appl. Chem., Lond.*, 1956, **6** (1), 11. The advantage of the impact mill over other methods of size reduction lies in the combination of high throughput, low-power requirement, low weight, small space requirement, freedom from clogging and easy replacement of worn parts. Breakage into cube form is of importance to some industries.

1489. **Some Thoughts on Coal Pulverization.** VERNON, P. V. *Engineer, Lond.*, 1928,

145, 176. Includes performance data for high-speed impact mill. 40 h.p. for 2 tons per hour, and 23 h.p. after deducting power for fans. [P]

1490. **A Small Laboratory Pulverizer.** WRIGHT, B. M. *Chem. & Ind.* (*Rev.*), 3 Jan. 1953, **26**, 8–10. An impact mill is described, having a rotor whose carefully balanced impact members throw the material against a specially-shaped peripheral stator which throws the material back to the rotor. Speed 20 000 rev/min, maximum size of product 10 microns. It is designed for pulverizing coal. Output is 200 g/h for steam coal, 20 g/h for anthracite. Full description and diagrams. 4 refs.

1491. **Pulverizers.** YOUNG, C. W. *Brit. Pat.* 578236, 1946. The pulverizer consists of rotors provided with peripheral pulverizing members rotating in parallel planes between one another, the two shafts rotating in the same direction. The rotor members may partially or wholly overlap. Either a high- or low-pressure fluid system (air) may be used, by which the particles are forced between pulverizing members moving in opposite directions. *See* Gillings, D. W., *J. Iron St. Inst.*, 1951, **167**, 400–39.

PINNED DISC MILLS

1492. **Grinding Free Flowing Materials.** *Edg. Allen News*, 1954, **33** (379), 6–8. A description of the two classes of pinned disc mills. Class A—the pins are supplemented by a circular grinding chamber at short radial distance from the periphery of the discs. Class B—there is no additional wall and so the material receives no further treatment after leaving the pins. The product therefore is not so fine. The details and performance of three sizes of each type are tabulated.

1493. **Impact Mill.** ANON. *Industr. Chem. Mfr.*, 1956, **32** (372), 44. The principle is to reduce by impact against the pins of two pinned discs mounted horizontally. Impact against the housing assists.

1494. **How Low-Density Solids are Made.** ABBOTT, J. A. *Chem. Engng*, 1952, **59** (7), 212–5. Deals largely with foams. Pressure drop, etc., in pin mills is also discussed.

1495. **Sieveless Centrifugal Mill.** ALPINE AG., AND RUMPF, H. *Brit. Pat.* 689936, 1949/53. The mill has two discs with grinding pegs, rotating on a horizontal axis. The housing is spaced far enough away for the particles to have lost their kinetic energy, and so avoid sticking to the walls, and to be carried away by the air stream. Fineness is determined by the speed of the discs and their relative direction of rotation, and rate of air flow.

1496. **Improvements Relating to a Crushing Mill.** STOLBERGER ZINK AG. für Bergbau und Huttenbetrieb (Aachen). *Brit. Pat.* 718936, 1952/54. The pin mill is provided with a centrifugal plate on which the feed falls, to be flung outwards against the discs. From these the material is flung back against the surface of an impact ring, or else particles are flung directly against the inner surface of an outer impact ring, to rebound on to the moving pins unless the fine material falls down towards the exit at the bottom of the mill. The shaft is vertical, and the feed is central on to the centrifugal plate.

BASKET MILL

1497. **Opposed Disc Rotor Type Centrifuge.** PAUL, C. F. *U.S. Pat.* 2502022, 1944. Two discs revolving in opposite directions are each provided with two shallow peripheral pockets. The material is fed from the central shaft and reaches the housing exit after attrition between the oppositely moving surfaces. *See German Pat.* 645522, 1935, Basket Mill.

1498. **Arrangement for Pulverizing.** UNIVERSITY PATENTS INC., New York. *German Pat.* 645522, 1937. A description of an improvement of the basket mill.

MISCELLANEOUS IMPACT MILLS

1499. **Toothed Disc Mills.** CONDUX-WERKE (Wolfgang, near Hanau). Dechema Exhibition, 1955. Illustrated pamphlet of various models. Very fine adjustment by hand wheel with counter attached for reproducible setting. Suitable for textiles, paper, wood pulp, leather, for continuous, fine, and uniform disintegration.

1500. **A Grinder Makes Uniform Fines.** CRONAN, C. S. *Engineering* (*Lond.*), 151–2. Three plates fitted with peripheral beaters or hammers revolve on a horizontal shaft in a housing fitted with an interchangeable fluted liner. An air flow carried the product through the mill by way of holes in the plates, into a combined classifier the rotor of which can be operated at speeds different from that of the grinding section. Classification is by inward movement of the air, and outward movement of the oversize and return to the feed end. It is claimed that sugar can be ground to 99·9% passing a 300-mesh sieve at 800 lb/h in a 20-in. diameter mill using 40 h.p., or 1300 lb/h at 99·7% –300-mesh product using 60 h.p. It is claimed to be suitable for pharmaceuticals, dried milk, etc.

1501. **Centrifugal Mill.** KLAGSBRUNN, J. and MARKUS, E. *Brit. Pat.* 683849, 1949/53. The mill has a stationary grinding unit provided with a number of chambers around its circumference into which material is thrown by rotating blades, oversize being returned after passing along the spirally curved inner wall of each chamber while the fine material is removed from the chambers by an air stream. Pulverization occurs by impact against the blade and wall and also by impact of the returned oversize projected into the main feed.

1502. **Centrifugal Mill.** KOHLENSCHEIDUNGS G.m.b.H. (Stuttgart). *Brit. Pat.* 720788, 1952/54. This mill, suitable for pulverized coal firing, consists of a paddle wheel with horizontal shaft with axial air blast and feed.

1503. **A reduction Mill.** LECHER, J. *Brit. Pat.* 696799, 1952. A vertical cylinder contains tiers of closely-spaced arms mounted on a vertical shaft revolving at high speed. A heavy iron plate is mounted at the end of each arm. A circular iron plate is attached below each tier of arms and revolving with them, thus dividing the total space into flat compartments. Access to each compartment is thus only by way of the periphery, up which an air stream carries the feed. The feed is caught in violent motion between the arm plates in successive tiers and partially dried and pulverized if fed alone, or else mixed or coated if fed in conjunction with other solid or liquid ingredients having separate access to the mill. A one ton per hour mill uses a 50-h.p. motor. The product fineness depends largely on air speed. Separation is done by conventional means.

1504. **Method and Apparatus for Reducing Solid Materials Utilizing Vibratory Shock Waves.** LECHER, J., MICROCYCLOMAT CO. *U.S. Pat.* 2709552, 1955. A stream of air carries the particles to be reduced to 1–3 mu upwards through a cylindrical casing past several tiers of revolving arms mounted on a central shaft. At the ends of each arm, of which some 25 are mounted on each circular tier, are attached flexible members, mounted in suitably-shaped clamps. These members vibrate at high speed by virtue of the rotation of the arms and the clearance between the members and the plain or corrugated inner shell wall. Deflectors throw the air stream outwards to the shell so that the material comes in contact with the vibrators. The movement of the vibratory blade is computed to be 460 ft/s. The movement of air increases the rate of impact by 166 ft/s.

1505. **Method and Apparatus for the Production of Fine and Ultra-fine Particles.** LECHER, J., MICROCYCLOMAT CO. *U.S. Pat.* 2752097, 1956. The method is that of carrying the solid into a dry gaseous fluid, subject it to collision with solid surfaces to effect fracture and disintegrate by subjecting the granules to intense sonic bombardment at a level of at least 120 decibels.

1506. **Grinding and Pulverizing Method and Apparatus.** MACARTNEY PATENTS, LTD. *Brit. Pat.* 639050, 1946/50. The material is fed from above into an inverted cone rotating inside a larger one, the latter rotating in the opposite direction. The material is flung to the wall of the outer cone.

1507. **The Commercial Production of Ultra-Fine Powders and Their Profitable Use in Industrial Processes.** MICRONIC PRODUCTS, LTD., London. Booklet, 1955, 16 pp. The material is carried by an air stream from the bottom of the cylindrical casing inwards towards the rapidly revolving shaft and out through the top. Attached to the shaft is a series of annular discs and *resilient vanes* with fine clearances. No diagrams. The air velocity produces an ultra-sonic vibration of the resilient vanes, which produce most of the breakage. Particles are also thrown outwards and hit the casing liners which can be specially shaped and are of hard, wear-resistant metal. The firm states that 3 cwt/h of zinc stearate and 10 cwt/h of cocoa-nut shell for the plastics industry can be accomplished with the normal 50-kWh input.

COLLOID MILLS

1508. **Grinding of Materials in Germany, 1939–1945.** *B.I.O.S. Report*, No. 1356, 1948, H.M. Stationery Office, p. 43. Pulping soft organic materials, minerals, and emulsification of oils. One mill consists of an inner cylinder rotating at 3000–10 000 rev/min inside a fixed cylinder. Comminution is due partly to abrasive seizure and partly to eddy effect, since the clearance is very small.

1509. **The Premier High Speed Colloid Mill.** ANON. *Chem. Prod.*, 1954, **17** (10), 388–90. The rotor is a frustrum of a cone; working surfaces can be varied between 0·003 and 0·03 in. Peripheral speed 11 000 ft/min. Horizontal shaft. Output of the series of sizes is 20–2000 gal/h.

1510. **Colloidal Chemistry and a Colloid Mill.** ANON. *Engineering, Lond.*, 1920, **60**, 429. A lengthy discussion of the remarkable claims made by H. Plauson on behalf of a new type of disintegrator, on which experiments were begun in 1911. With dry grinding of coal, talc, graphite, etc. sizes down to 1 micron were reached. With wet grinding 0·1 micron is claimed. The results obtained by use of various disperse media, accelerators and protective colloids, proportions of media and the adverse effects of electrolytes, etc., are discussed.

1511. **Symposium on Nucleation.** *Industr. Engng Chem.* (*Industr.*), 1952, **44**, 1269–1340. An understanding of nucleation processes is fundamental in the preparation of all types of colloid suspensions.

1512. **Colloid Mills: Grinding Experiments with Dyestuffs.** Microfilms of German Documents. Obtainable in microfilm or photostat form from: Lending Library Unit, D.S.I.R., Ref. FD1157/50, Frames 2460–76.

1513. **Some Experiments on Colloidal Grinding with a Ball Mill.** ANDREASEN, A. H., BERG, S. and KJAER, E. *Kolloidzschr.*, 1938, **82**, 37. A 5-litre porcelain drum was used for the experiments at the critical speed of 99 rev/min corresponding to $n=k/D$, with $k=42{\cdot}3$ and in which n=rev/min and D=the diameter. A large number of small steel balls (7·94 and 3·93 mm diameter) occupied 37·3% of the volume of the drum. The materials were finely-ground heavy spar and polishing red, chosen because the iron impurities introduced during the grinding could be removed without serious attack on the particles. The method of carrying out the analysis is described. Polishing red was more difficult to grind than heavy spar. Further, the smaller balls were more effective than the larger, but to a much less degree with polishing red than with heavy spar. The difference in the finest grain sizes was up to 50% with heavy spar and less than 10% with polishing red. Into the latter 4% of iron was introduced during the grinding, but only 1% into the spar. After 24 hours' grinding 20% of the spar was

below the 0·1 μ size, after 27 hours 48%; in the polishing red this fraction made up 15%. With usual porcelain balls practically none of this fraction is obtained.

1514. **The Colloid Constituent of Material to be Ground.** ANDREASEN, A. H. M. *Ber. dtsch. keram. Ges.*, 1938, **19**, 23.

1515. **A New Colloid Mill.** AUSPITZER, OTTO, ODERBERG CHEMISCHE WERKE, AG., Neu Oderberg, Czechoslovakia. *Industr. Engng Chem.* (*Industr.*), 1928, **20**, 413–15. The corrosion and wear observed in the types of Plauson mill used to date indicated that much power was wasted through friction. The Oderberg mill is an attempt after many futile efforts to reduce this friction while using the Plauson beater principle. In the Oderberg mill the material is conducted tangentially past the beaters, the mill chamber being empty and thus there is no rotation of bulk material as in previous mills. The material passes through the mill slowly, so that the benefits of full rotational velocity of the blades are obtained. These are at the periphery of the housing and not on an eccentric shaft. The Oderberg mill is claimed to use only one-seventh of the power of the Plauson mill for equal output. Diagrams of mill and of settling tests on product.

1516. **The Colloid Mill and its Use in the Chemical Industry.** BLOCK, B. *Z. angew. Chem.*, 1921, **34**, 25. A general account of the process as worked out by H. Plauson.

1517. **A Colloid Mill in Laboratory Glassware.** BOYE, E. *Chemikerztg*, 1950, **74**, 721; *Chem. Abstr.*, 1951, 4493. The apparatus has two oppositely rotating discs on a concentric axis with several slotted rings attached to one face and moving in the annular space between a pair of similar rings attached to the opposite disc. The material is thus forced through several changes of direction as it passes between the discs. Stable emulsions of water and oil can be prepared without emulsifying agents. Colloidal dispersions of sulphur, graphite and pigments in water can be made. Sizes range from 250–1000 c.c.

1518. **Dispersing Clays in a Colloid Mill.** BURDICK, R. *Bull. Amer. ceram. Soc.*, 1945, **24**, 160. The use of the colloid mill for dispersing clay slips results in greater effective fineness of the clay. Grinding of coarse shale and sand particles is accomplished, but the ultimate particle size of the very fine fractions is not greatly changed by the colloid mill. Dry and fired strengths can be improved by colloid milling. Drying shrinkage is changed to no great extent, firing shrinkage tends to be increased, and fired absorption tends to be lowered by colloid milling. Colloid milling should be most advantageous when dispersion of a clay in a medium of low pH is desired.

1519. **Colloid Mills.** CHINA, F. J. E. *Brit. Pat.* 675690, 1952. This is a dispersing mill, into which the material is fed vertically and regulated by passing between rollers before dropping on to the horizontal rotor. The working surface of the rotor can be leather felted asbestos, wool felt, rubber, etc. The drawing shows the method of attachment of the working material to the periphery of the rotor, and how the vertical (outside surface) of the working material moves in contact with the inner wall of the housing.

1520. **Fine Grinding Apparatus.** DICKINSON, W. H. *Brit. Pat.* 611583, 1946/49. A tapered drum rotates inside a hollow tapered drum. The clearance is therefore adjustable. Grooves run the length of the inner drum, alternate ends of the grooves being closed to achieve inlet and outlet. Scrapers are fitted to the outlet grooves.

1521. **The Colloid Mill.** FORSTER, A. and REILLY, J. *J. Soc. chem. Ind., Lond.*, 1922, **41** (20), 435R–438R. After reviewing the size limitations of dry grinding, the authors refer to the work of Dr. Plauson on fine grinding in liquid media by two methods: (1) between rotating discs, (2) by the Plauson colloid mill. This is a standard design embodying improvements to date and consists of an eccentrically-disposed beater wheel whose beater arms revolve at high speed between baffles at small clearance disposed above and below the beater wheel. The pulverized material in the desired

liquid is fed into the top of the housing. Methods of operation, precautions, etc., are described and a long list of materials which can be treated and with their applications is included. The numbers of 12 English and 6 German patents are given. References to original work are given: *Z. angew. Chem.*, 1921 (25), 34; 469–73. The Colloidal Mill and its possibilities, by H. Plauson; (25), The Colloidal Mill and its applications in chemical technology, by B. Block.

1522. **Colloidal Disc Grinding Mills.** U.S. FUEL RESEARCH CORPORATION. *Brit. Pat.* 592828, 1944. The invention relates to wet, high-speed colloidal disc grinding mills with feeding under pressure.

1523. **Improvements in Grinding Discs.** U.S. FUEL RESEARCH CORPORATION. *Brit. Pat.* 643249, 1950. *See under* Disc Mills.

1524. **High-speed Dispersing Machines (Colloid Mills).** GROHN, H. *Chem. Fabr.*, 1931, 1–4, 13–15, 27–28. The pioneer work of Plauson is described. Colloid mills fall into two classes: (1) beater mills, such as the original Plauson mill; (2) mills in which the dispersion is forced through a slit as a thin film by high-speed rotors. Several mills of the first class, including some operating by centrifugal force, are described. Those of the second class (Premier mill and others) are especially suited for the preparation of emulsions. The improvements made in the Plauson mill are chiefly concerned with the increase of speed and reduction of power requirements. The eccentric position of the beaters was retained, although it involved a circulating of the liquid within the mill, which absorbed power. In the Oderberger colloid mill, however, the liquid is immediately removed by a pump, the action of the beaters being merely dispersive. The various theories of the action of the beater mill, as proposed by Plauson, Block and others, are reviewed and criticized. Travis' view, that colloid mills only deflocculate secondary aggregates without breaking up large primary particles is not accepted. The 'vacuum dryer colloid mill' effects improved results by forcing the liquid in counter-current to the direction of movement of the beaters, and by the use of subsidiary additional beaters. Probably dispersion is a function of relative velocity, beaters and liquid, and of the number of impacts.

1525. **Colloid Grinding Arrangement.** HEBLER, F. *Farbenztg*, 1929, **34**, 834; *Paint Oil chem. Rev.*, March/April 1929, 97. Viewed from the technical and economic aspect. Results from ball mill and Plauson mill show that the former gives greater dispersion if time is long enough, and even if 7–20 times as long, the power consumption is less than in the colloid mill.

1526. **Colloid Mill for Bituminous Emulsions.** KHUDYAKOV, A. N. and LAMBERG, B. A. *Hydrotech. Constr.* (*Gidrotekh. Stroitel.*), 1948, **18** (9), 30–1; *Chem. Abstr.*, 1950, **44** (9), 4236h. A centrifugal mill with conical smooth surfaces is described.

1527. **Design and Operation of a Colloid Mill.** MCLEAN, W. A. *Chem. metall. Engng*, 1924, **30**, 675–7. Describes a mill invented by F. J. E. China, of London, and used commercially for a year. The mill will disintegrate solid, plastic or liquid masses into colloidal particles whose dimensions are one micron or less in diameter. In design the mill consists of a rotor with a smooth face upon the frustrum of a cone, turning within the similar surface of a stator, the whole enclosed in a casing. Thus there are two variables in operating the mill; the clearance between rotor and stator, which may be from 0·002 in. up, and the speed of rotation, which may vary from 1000 to 20 000 rev/min. Solids must first be ground to about 150-mesh and suspended in a liquid medium. The centrifugal action of the rotor sucks the liquid through the inlet at the bottom of the mill, through the space between rotor and stator, and out through a discharge above the rotor. From 1 to 2·5 tons of feldspar per hour may be ground to colloidal fineness, with the passage of 3·5–5 tons of water medium. A discussion of the disruptive forces used by the mill is given, together with figures on power consumption.

1528. **Method of Grinding Solids to an Extremely Fine State and Preparing Colloid Solutions.** ODERBERG CHEMISCHE WERKE AG. *French Pat.* 605655. *Le Caout*, 1927, **24**, 13776.

1529. **Progress in Particle Subdivision.** OSTERMANN, W. *Farbenztg*, 1925, **30**, 1873; *Chem. Abstr.*, 1925, **19**, 2584. Brief review of the general methods of producing the colloid state, and types of colloid mills.

1530. **The Colloid Mill and the Possibilities of its Practical Application.** PLAUSON, H. *Chem. Z.*, 1920, 553–67; *Chem. Tr. J.*, 16 Oct. 1920; *Chem. Age, Lond.*, 25 Oct. 1920; *Z. angew. Chem.*, 1921, **34**, 469–73. The authors' improvements on the disc and beater types of G. Hanning, *German Pat.* 289026, 1914/16, are fully described. The capabilities of the mills (reduction to 0·1 micron) and many types of application of the mills are discussed, one of the most important to the preparation of colloidal coal.

1531. **Process and Apparatus for the Manufacture of Dispersoids.** PLAUSON, H. *U.S. Pat.* 1500845, 1921/24. 5 designs of mill are described and illustrated, 4 of the beater type, one with smooth surfaces, and all with eccentric beater shafts.

1532. **Mechanical Reduction to the Colloid State.** PODSZUS, E. *Kolloidsschr.*, 1933, **64** (2), 129–43. Although the aim of size reduction is a desired particle size, the product is normally heterogeneous. The author discusses the conditions for grinding to colloidal size, and shows that theoretically, little energy should be required. Grinding to colloid size, however, consumes large amounts of energy which are usually impractical. The author describes a whirling mill which rotates so fast that the material is reduced to a thick cloud of particles. The machine and applications are described in detail. 3 figs.

1533. **Improvements in Grinding Mills.** ROBINSON, E. S. & A., LTD. *Brit. Pat.* 646526, 1948/50. This mill is suitable for pastes, and consists of a rotating conical horizontal member, the material being pumped into the narrow end and ground in the annular space by the conical member which is not quite concentric with the housing. Special discharge arrangements are provided.

1534. **A Small Laboratory Colloid Mill.** ROSENFELD, L. *Chem. & Ind.* (*Rev.*), 1950, **31**, 591–2. For dispersing very fine solids in, say, oils, the mixture is passed through a narrow gap between a rapidly rotating rotor and stator, the gap being a horizontal ring between the lower parts of the stator and rotor, variable between 0·002 and 0·006 in. The spindle is motor driven and at a gap of 0·002 in. and a speed of 5000 rev/min a rate shear of about 200 000 cm/sec is obtained and a dispersion to sizes between 6 μ and 0·1 μ.

1535. **Developing the Colloid Mill.** SCHOTZ, S. P. *Crush. & Grind.*, 1931, **1**, 31–2. A brief description of the early colloid mills, from the 1913 Plauson disc type, which made no impression, to the post-war 'hydraulic crushing' machine, in which particles could be reduced to 0·1 micron according to the speed of the rotor periphery. Lastly the Plauson-Block mill driven at 12 000 rev/min by an 80-h.p. steam turbine. The defects of this mill are enumerated.

1536. **Mechanical Dispersion by Means of a Colloid Mill.** TRAVIS, M. *Industr. Engng Chem.* (*Industr.*), 1929, **21**, 421; *J. Text. Inst.*, 1929, **20**, 464A. Historical survey of the apparatus with a description of its capabilities. Several types of mill are illustrated, the main features being (1) the beater principle of Plauson mill, (2) opposed surfaces, either rough or smooth, disc or conical in form, working at high speed and small clearances 0·002–0·008 in., and (3) the turbine mill, which can embody the beater, with rough or smooth surfaces, is continuous but not adjustable for wear. It is emphasized that a colloid mill is a dispersion or deflocculating mill only and is not a grinding mill. Adequate knowledge of colloid chemistry is requisite for success for

these mills. 5 refs. The paper does not deal with 'pressure colloid mills' as widely used as homogenizers at 2–3000 lb/sq. in.

1537. **Process for Manufacture of Dispersoids.** TRAUN, H. O. *Engl. Pat.* 155836, 1919/22. Four types of Plauson mill are illustrated and described, all on the beater principle. The method of dispersal and the addition of protective grinding aids are included and described in the specification.

Non-mechanical Methods

GENERAL PAPERS

1538. **Non-Mechanical Methods of Size-Reduction.** MURPHY, E., ROSS, F. F. and SHARPE, G. C. H. *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1947, **11** (7), 221–33. There are three processes by which solid particles may be reduced in size without the use of mechanical mills. These processes will be termed: 'impact', by which is implied the impact of the particles on a comparatively large solid surface; 'attrition', i.e. the rubbing of particles on each other or collisions between them; and 'explosion', i.e. the disruption of the particles from within by a sudden release of pressure without. These three processes and the mills which make use of them are described. Control of output and of fineness of product and power consumption in non-mechanical pulverizers are also referred to. 7 diagrams of the three types, and a tabular comparison of dimensions, power consumption, uses, etc., are presented. 25 references and a list of over 60 patents, German, British and U.S.A. [P]

1539. **Impact Mill. A New Development in Crushing Technique.** TORLACH, A. *Z. Ver. dtsch. Ing.*, 15 May 1955, **97**, 493–6. The process leads to natural separation at grain boundaries, and is applicable to a variety of materials.

AIR AND STEAM JET MILLS, WITH ANVIL

1540. **Some Novel Methods of Coal Pulverization.** ANON. *Engng Boil. Ho. Rev.*, Nov. 1946, **61**, 147–53. Description of the German-built 'Angers' pulverizer. Development, design and operation of coal pulverizer are described.

1541. **Recent Advances in Crushing and Grinding.** DEAN, R. S. *Bull. Amer. ceram. Soc.*, 1937, **16**, 9. Deals, *inter alia*, with crushing by impingement on a plate. 286 lb of dolomite can be reduced to −400 mesh in one hour, when fed into a high-velocity gas stream and blown from a $\frac{5}{8}$-in. nozzle.

1542. **Experience with Pneumatic Mills. (Prallmuhlen.)** ENGEL, J. *Wärme*, 1942, **65**, 73–6. The mode of action of the Angers Mill is described, but most of the paper discusses experimental results and also gives a graphical representation of the data obtained. [P]

1543. **Pulverizing of Solids.** INTERNATIONAL PULVERIZER CORPORATION, New Jersey. *Brit. Pat.* 592967, 1947. An apparatus which impels particles in a high-velocity gas jet against a block or anvil, situated below or above the jet. An exhaust from the anvil chamber classifies the product and returns the oversize.

1544. **A Contribution to the Subject of Wear in Coal Grinding Equipment.** KNOCH, F. *Feuerungstechnik*, 1942, **30**, 135–39. Includes a discussion of wear in the Angers Mill.

1545. **Size Reduction Tests in a Steam Plant at Cuno Werke.** MARCARD, W. *Arch. Wärmew.*, 1933, **14**, 313–16. The new works showed increased efficiency over the original 1928 works. Both used pulverized fuel but in addition to the tube mill, the new works produced a finer product by use of a second mill in which the ground particles were impelled by a steam jet against a plate, the first application of such a mill. The results of four investigations are tabulated under ten headings, giving in all 240 items of operational data. Efficiency rose from 87 to 89%. Diagrams. [P]

1546. **Jet Impact Pulverizer.** MICRONISER Co. *U.S. Pat.* 2487088, 1949; *Off. Gaz. U.S. Pat. Off.*, 1949, **628** (2), 381. A gas jet blows the wet solid against an anvil. Oversize material is returned.

1547. **Experience with Jet-Percussion (Fuel) Mills.** Rammler, E. and Engel, J. *Braunkohle*, 1941, **40**, 413–21. A general description is given of fuel mills in which use is made of the kinetic energy of a current of air by means of which the fuel is projected violently against a fixed shield, the main advantage being that the mill contains no movable parts. Test data relating to the sizing of brown coal and brown-coal coke are given. The surprising changes in throughput and power consumption when shields of various designs were fitted indicate that further developments in the method are possible. [P]

1548. **Grinding Tests with Low Temperature Coke and Dry Brown Coal in Angers Mills.** Rosin, P. and Rammler, E. *Braunkohle*, 1934, 33, 449–55, 467–74, 487–90. The chemical and physical properties of the milled products are tabulated and the applicability to various purposes is discussed. It is concluded that coke gives a product from the high-velocity air blast against the plate which is suitable for firing, briquetting, etc. With brown coal, however, the high temperature of the air blast cannot be tolerated. [P]

1549. **Investigations with a Pneumatic Pulverizer Prallmill.** Rosin, P. and Rammler, E. *Arch. Wärmew.*, 1935, **16**, 13. Data are given in the text and graphically for an Angers and Kallbohm pneumatic impact pulverizer with coke and brown coal reduction, in respect of feed, product, temperature characteristics, dimensions, capabilities and applicability. [P]

1550. **Pulverization of Coal with Steam.** Selezner, V. V. *Energetik* (*Power Engineering, Moscow*), Mar. 1955, 10–12; *Fuel Abstr.*, Aug. 1955, 1528. (Against a horizontal plate.) *See under* Coal.

1551. **Further Development of the Pneumatic Impact Mill. (Prallzerkleinerer.)** Weiss, K. *Arch. Wärmew*, 1944, **25**, 125–8. Describes a new design, with diagrams, of a longer mixing tube, and compares this with an earlier type of Angers Mill. Comparative performance data for both types are tabulated under 26 items. [P]

AIR AND STEAM JET MILLS, WITHOUT ANVIL

1552. **Steam Jet Coal Pulverizers.** *Blast Furn.*, 1947, **35**, 470–2.

1553. **Steam or Compressed Air in a Pneumatic Ring Mill for Micron Size Grinding.** *Chem. Engng*, 1950, **57** (2), 142. A description of the R. T. Vanderbilt plant for grinding large quantities of talc to fine sizes. Nozzle pressure up to 200 lb/sq. in. for superheated steam gives a steam velocity of 1000–3000 ft/s and a circulating velocity up to 400 ft/s. Drying can be done at the same time. Materials from abrasives to insecticides can be pulverized, using steam or air as appropriate.

1554. **Du Pont Tries a New Route to Synthesis Gas.** Anon. *Chem. Engng*, Mar. 1954, 114. Du Pont will be pulverizing its coal in fluid energy mills using steam as the high-velocity fluid. This is prior to combustion in steam and limited oxygen, in a modified steam tube boiler with slagged ash.

1555. **Kidwell Reductionizer.** Anon. *Paint Manuf.*, 1950, **20** (6), 212–3. Attrition is done in a curved tube by steam or air down to an average of 1 micron. Classification is by centrifugal action and the finest particles removed. The apparatus is in the form of a loop disposed vertically, with several nozzles for steam or compressed air (100 lb/sq. in.) injection as well as a feed inlet.

1556. **These Ultrafine Fillers are Micro-Minerals.** Anon. *Rubb. Age, Lond.*, 1939, **20** (3), 87–8. The finest particles so far obtainable are 325 mesh or 44 microns. A new method grinds to 20, 10, 5 or 3 microns, according to need, by projection of particles into a hot air stream. Asbestos, talc, limestone, dolomite, barytes, mica and sulphur are marketed in this form. Micro dolomite is only half the price of $MgCO_3$ and gives

compounds with higher tensile strength and better elasticity. Materials are very suitable for latex compounding. Photomicrographs.

1557. **Blaw Knox Steam Jet Pulverizer.** ANON. *Steam Engr*, 1947, **16** (8), 432–3; (11), 71–2. Two models are made, a circular and loop model. The fuel, of $\frac{3}{8}$-in. size, is fed by a screw feed to meet four impinging superheated steam jets at 700°–800°F. The broken material passes round the duct for further breakage until fine enough to pass out at the top of the pulverizer. The steam can be separated before being fed to the burners. Capacity up to 10 000 lb/h.

1558. **Method of, and Apparatus for, Providing Material of Finely Divided Form.** ANDREWS, W. H. International Pulveriser Corporation. *U.S. Pat.* 2032827, 1936. To avoid the wear on baffle plates on the one hand, and the uncertain efficiency of impinging jets on the other, the present invention is concerned with a vortex produced by spirally-arranged jets and baffles for producing turbulence. 18 pp.

1559. **Drying and Pulverizing Method and Apparatus.** ANDREWS, W. H. and SPEIRS, J. L. *U.S. Pat.*, 2494153, 1945/50. Description of the circular grinding chamber with peripheral inlets of gases and material and outlet for classification by cyclone, which is also described.

1560. **Fluid Energy Pulverizer.** BECHTEL, L. D. and CROFT, G. M. *Blast Furn.*, Oct./Nov. 1950, **38**, 1190–2, 1332–5; *Mech. Engng, N.Y.*, 1950, **42**, 742–4. Its relation to steam generation is discussed. Steam or air jets can be used, and the particles separated from the exhaust by a rotating blade classifier. With superheated steam at 750°F it is possible to dry while pulverizing. For bituminous coal 0·4 pounds of steam per pound of coal are required for a product of 90% through 200 mesh or only 0·2 pounds for 70% through 200 mesh. Two applications are described and test results given. [P]

1561. **Fluid Energy Mills.** BERRY, C. E. *Chemical Engineers Handbook*, 1951, Perry, J. H. Fluid energy and jet mills are described, and tabulated data are given of the performance of the micronizer working on materials of $\frac{1}{4}$ in. diameter with steam and air media. A reduction to less than 5 μ from a 10-mesh feed is claimed for these mills, using from one to ten times the weight of fluid at a feed pressure of 100 lb/sq. in. Internal classification and continuous withdrawal of fines is arranged. The method is not suitable for rubbery, fibrous or resilient materials. [P]

1562. **Fluid-type Attrition Mill and Separator.** CROWLEY, H. L., MOSTHAF, E. F. and HENDERSON, A. S. *U.S. Pat.* 2521000, 1950. This attrition mill has a closed circulatory path for the gaseous medium and the solid material which is to be comminuted and is held in suspension in the gaseous medium. This path is in the form of a vertical leg of large cross-section, intersected by a substantially horizontal leg, and a return portion connecting the upper end of the vertical leg with the horizontal leg at some distance from the intersection with the vertical leg. The gaseous medium and the solid to be comminuted are introduced into the path at a point remote from the vertical leg and propelled from the horizontal leg towards the vertical leg by means of a fan. Near the bottom of the vertical leg a propeller type axial flow fan, which causes an upward flow of the circulating medium and suspended material, and creates a zone of turbulence in the vertical leg near its intersection with the horizontal leg, in which zone the desired comminution is effected. The gaseous medium and comminuted material are removed at a point between the vertical leg and the point of introduction.

1563. **Industrial Grinding and Reduction Plant Parts 1 to 5.** DARLING, C. S. *Mech. World*, 1948, **123**, 371–6, 418–22, 447–52, 506–10, 555–8. Describes the mills available for crushing minerals, and deals particularly with fluid-type mills, e.g. the Micronizer, Kidwell mill and Blaw-Knox mill, the material being steam or air borne. The Blaw-Knox mill is a combination of the micronizer (flat ring chamber) and the Kidwell mill (closed loop circuit of pipes).

1564. **Motion of Fluid in a Curved Pipe.** DEAN, W. R. *Phil. Mag.*, 1927, 4, 208; 1928, 5, 673.

1565. **Ultra-fine Grinding and Classification with Fluid Jet Pulverizers.** DUFOUR, M. F. and CHATELAIN, J. B. *Min. Engng, N.Y.*, 1952, 4 (3), 262–4. This is a description of the micronizer fluid energy mill, which has a relatively flat cylindrical grinding chamber. Micronizers are rated according to the inside diameter of the grinding chamber, which may be from 2–30 in., the number of grinding jets varying from 3–24. The capacity of different sized micronizers, and energy requirements for grinding a number of different materials are shown in a table (chalk, limestone, not included). It is an advantage to precrush the material to at least 10 mesh, sometimes 100–200 mesh. 90% reduction occurs within a fraction of an inch of the orifice. Integral cyclone can effect 85% efficiency separation with 2-mu particles.

1566. **Improved Method of Attrition, and Mill for Effecting the Same.** EAGLE PENCIL Co., U.S.A. *Brit. Pat.* 546474, 1942. Graphite, clay, coal, sandstone, cement, ore, etc., are pulverized by drawing a compact body of the comminuted material in a gaseous stream through a metal pipe. Attrition occurs between the particles, and the system is kept under reduced pressure in a closed system.

1567. **Super Pulverization of Small Anthracite.** HAMMOND, E. S., BLAW KNOX CO. *U.S. Pat.* 2385508, 1946; *Fuel Abstr.*, Feb. 1946, 416. Finely-ground coal is blown by superheated steam into a loop of steel tubing, flow being maintained by additional jets. The particles impinge on one another and become superfine, and if blown directly into the furnace box they burn with approx. the same thermal efficiency as gas.

1568. **Grinding and Pulverizing Apparatus.** INTERNATIONAL PULVERISER CORPORATION. *Brit. Pat.* 567453, 1945. A horizontal jet mill with vertical spindle, in which at least part of the containing wall is made to revolve and thus increase output. This is attained by arranging for the floor of the chamber to be revolved about the vertical axis. This results in oversize being returned more quickly.

1569. **Studies on Pulverizing by Vortex in a Pipe.** KAYOJI, N. and KOGURE, K. *Trans. Soc. Mech. Engrs, Japan*, 1952, **18** (66), 185–90; *Japanese Science Review* (*Engineering Science*), Dec. 1952, 21. In a closed circuit pulverizer, the product from bituminous coal was found to have a size distribution which conformed to the Rosin–Rammler formula $R=100e^{-bx^n}$. The exponent n was 0·44 as compared with a ball mill product value of about 1·0. Further, the value of b was nearly proportional to the applied energy and was about the 0·7 power of the charging rate of the particles. From these and other observations it has been possible to design the apparatus and its operation.

1570. **Fluid Energy Mill, for Grinding to Sub-sieve Range.** KINGSTON, H. E., BERK, LTD. *British Chemical Engineering*, May 1956, **1** (1), 30–3. The applications and capabilities of the micronizer are described, both for jet feed and worm feed. Illustrations are given of the mill and of plant layout, particularly that fitted with explosion suppression devices for grinding explosion-prone materials. The effects of all variables are discussed in detail and the advantages of steam as against compressed-air operation are described. A general guide to size of mill and grinding energy requirements is given:

Size of Mill, in. (diameter)	Air Blast, cu. ft/min	Steam Requirement lb/h
2	20	—
4	40	—
8	100	250
12	225	600
15	350	900
20	550	1500
24	1000	2600
30	1500	4000

Air volume at N.T.P. Used at 100 pounds per sq. in. gauge.
Steam supply at 150 pounds per sq. in. gauge and 550°F.
Output Range:
$\frac{1}{2}$ to 4 lb/h for the 2-in. mill, and
500 to 3000 lb/h for the 30-in. mill.

1571. **Pneumatic Mill Developed by All-Union Thermo-Technical Institute.** KISELHOF, M. L. *Bull. All-Un. Heat Engng Inst.* (*Izv. vsesoyuz. teplotekh Inst.*), Jan. 1946 (1), 5–11; *Engrs Dig.*, Aug. 1946, 7, 242–4. A description is given of the pneumatic mill first installed to operate in conjunction with a Loeffler boiler at the No. 9 Mozenergo plant. Besides diagrams of the mill and of a pulverized coal preparation plant for the boiler there are graphs showing the relationships between mill output and fineness of final product, flow resistance of mill, specific power consumption and initial size of coal.

1572. **Influence of Particle Size Distribution on the Properties of Nepheline Syenite.** KOENIG, C. J. *J. Amer. ceram. Soc.*, 1955, **38** (7), 231–41. Samples of nepheline syenite prepared by conventional and fluid energy reduction methods were studied to determine (1) their fundamental properties and (2) the characteristics they impart to vitreous bodies. Fluid energy methods make it possible to obtain materials which will pass a 325-mesh sieve and yet do not have excessive amounts of fines. The largest particles by conventional grinding have more than 100 times the volume of the largest particles prepared as above. Fluid energy particles have lower bulk densities than conventionally-ground samples. The improvements in the resulting white ware are itemized. The mill used was a vertical loop mill with classifier outlet. Illustrations, 12 graphs, 6 tables. 18 refs.

1573. **Size Reduction Tests in a Steam Plant at Cuno-Werke.** MARCARD, W. *Arch. Wärmew.*, 1933, **14**, 313–6. *See under* air or steam jet mills with anvil.

1574. **Drying and Pulverizing Apparatus. Improvements Relating to Circulatory Pulverizing Mills.** MICRONISER CO. *U.S. Pat.* 2494153, 1950; *Brit. Patents* 639762, 1950, 660674, 1951.

1575. **Jet Milled Pigments.** MOORE, C. W. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1950 (304), 373–80. The milling with jets (moving at about 300–600 mile/h) is not adapted commercially for ultra-fine size, under 1–2 microns. The particles produced are smooth ovals or spheroids, without cracks or jagged edges. This reduces oil absorption. In the process, the particles lose most of their entrained and absorbed moisture, and, it is thought, the adsorbed layer of gas and moisture as well.

1576. **Steam or Compressed Air Used to Drive Fluid Energy Mill for Micron Size Grinding.** OLIVE, T. R. *Chem. Engng*, 1950, **57** (2), 142. With −4-mesh particle feed controlled size material of 1–2 microns are removed through a classifier at the inside of the bends. Power consumption data are given. Process is suitable for pigments, face powders, abrasives, insecticides, etc. [P]

1577. **Combustion Apparatus for Burning Solid Fuel in Comminuted Form.** POWER JETS, LTD., WINTER, E. F. *Brit. Pat.*, 659094, 1950. The use of a vortex chamber for pulverizing coal and its combination with a combustion chamber so that the maximum particle size of the product is controlled. Reduction is by mutual attrition assisted by wall serrations to promote turbulence.

1578. **Improvements in or relating to the Grinding or Pulverizing of Minerals and Similar Materials.** PROCTOR, H. A. *Brit. Pat.* 636503, 1950. The material passes with air or steam in a spiral path provided with deflector ledges or ribs and spirally arranged jets discharging the pressure fluid. A classifier and coarse return are incorporated.

1579. **Some Experiences with Fine Grinding.** SPEIRS, J. L. *Ceramic Age*, 1942, **40**, 37. Discussion of the superiority of the newer closed-circuit grinding over the older methods of open-circuit grinding used in the ceramic industry. In spite of valid objec-

tions from the ceramic industry closed-circuit grinding retains superiority. The author then discusses the 'Micronizer' reduction mill, especially for colours and chemicals, although pigment colours can deteriorate under certain conditions. By this mill, silica and lignite can be removed from crude enamelling clay, and retained in the circulating load because of higher density. The grinding cost is relatively high.

1580. **Process for Subdividing Solid Particles.** STANDARD OIL DEVELOPMENT CO. *U.S. Pat.* 2568400; *Off. Gaz. U.S. Pat. Off.*, 1951, **650** (3), 818. Particular features: Fluidized state in a hopper, separation by segregation, mechanical breaking of particles, introduction into fluid stream under pressure, and passage through a jet.

1581. **Method for Feeding Fuel.** STEPHANOFF, N. N. *U.S. Pat.* 2550390, 1944/47. Pulverization by high-pressure steam or other gases. *See under* Coal.

1582. **Process for Disintegrating Crushed Materials.** TEXACO DEVELOPMENT CO. *Brit. Pat.* 683318, 1951. The method is by dispersion in steam. *See under* Coal.

1583. **Apparatus and Method to Comminute Solid Particles in Gas.** TANNER, H. G. *U.S. Pat.* No. 2552603, 1951. This method of comminuting finely-divided particles into substantially smaller particles comprises agitating finely-divided particles in a gas under compression, so that the particles are suspended in the gas; passing the gas with the particles in suspension through a narrow annular turbulent zone, having a width not in excess of ⅛ in., and bonded on the outside by a rigid, stationary surface and on its inside by a hard, smooth surface moving at a speed of not less than 100 ft/s.

1584. **New Fine Grinding Method.** TRAUFFER, W. E. *Pit & Quarry*, Aug. 1950, **43** (2), 58–62. An account of the preparation of talc at the Gouverneur Talc Corpn. The ore is reduced respectively in a jaw crusher, cone crusher, a conical flint pebble mill and finally in a fluid energy mill. This is a vertical closed-circuit tube 8 ft high in which a hot-air blast at a speed of 1600 ft/s. meets the feed at 100 or 200 mesh size from the ball mill and reduces it to micron size. Three grades are prepared: 6, 1·5 and 0·8 microns. With the air circulating at 150–400 mile/h up to 6 tons may pass a given point in one minute, although only a few pounds are present at any one time in each of the 14 Wheeler fluid energy mills. Drying can be done at the same time. See also *Chem. Engng*, 1950, **57** (2), 142 (Wheeler Corporation).

1585. **Jet Mill Grinding.** FROST, C. M. *Science*, 6 Feb. 1953, **117**, Suppl. 3. A short account of the main features and costs of jet mill grinding. The air consumption varies from 20 cu. ft/min to 2000 cu. ft/min at pressures of 50–150 lb/sq. in. The emitted air velocity may be as high as 3000 ft/s at the nozzle, and the load velocity up to 400 ft/s. Product size 20–10–5 microns or less. Costs to very low micron sizes range from 1 to 10 dollars a ton according to the nature of the material, and say 3–5 dollars a ton for limestone, but costs vary widely according to size requirements. In general, rubbery, some fibrous or very resilient materials cannot be handled.

1586. **Pulverizing Mill having Opposed Jets and Circulatory Classification.** FROST, C. M. *U.S. Pat.* 2704635, 1955. An opposed jet device is used to improve the product from a loop pneumatic mill in respect of increased output, more uniform and small size, and less oversize in the product.

1587. **Stream Line Flow through Curved Pipes.** WHITE, C. M. *Proc. roy. Soc. A.*, 1929, **123**, 645.

EXPLOSIVE SHATTERING

1588. **Explosive Shattering of Minerals as a Substitute for Crushing, Preparatory to Ore Dressing.** DEAN, R. S. and GROSS, J. *Rep. Invest. U.S. Bur. Min.*, No. 3118, 1932.

1589. **New Ideas in the Preparation of Ore for Milling.** DEAN, R. S. and GROSS, J. *Canad. Chem. Metall.*, 1932, **16** (3), 71–2. Explosive shattering is discussed on the basis of a microscope examination of typical mineral sections. The energy required

is calculated approximately from known steam values, and taking into account the heat of vaporization against the atmosphere, the steam requirement per ton of ore is calculated to be 97 000 B.t.u. or 7 lb of coal. Thus the costs are competitive with conventional shattering methods. A detailed design of the experimental crushing machine is given.

1590. **Explosive Shattering of Minerals.** DEAN, R. S. and GROSS, J. *Rep. Invest. U.S. Bur. Min.*, No. 3201, 1933. The mechanism of shattering is described and the effects of variables are discussed.

1591. **Recent Advances in Crushing and Grinding.** DEAN, R. S. *Bull. Amer. ceram. Soc.*, 1937, **16**, 9. The theory of the laws of crushing is discussed, and the complete crushing law for a solid is given as: $kW=S+(iS)^2$. The problem of comminuting plastic solids is to apply large forces efficiently to fine particles. Two new methods of doing this are described, i.e. explosion shattering and nozzle crushing. In explosion shattering, the material is fed into a closed chamber and subjected to a pressure of several pounds of saturated steam. Water is thus condensed on the surface and in the pores of the material; the pressure is released suddenly and the expansion of the superheated water shatters the mineral. This method has the advantages of giving a dry product, and the quantity of very fine material produced is much less than when ordinary grinding methods are used. In the nozzle-crushing method, the material, reduced to less than 3 mesh, is fed into a high-velocity gas stream and allowed to impinge on a hard metal plate. With a nozzle of $\frac{3}{8}$ in. diameter, 286 lb of dolomite can be reduced to -400 mesh in 1 hour.

1592. **Progress in Explosive Shattering of Minerals.** GROSS, J. *Rep. Invest. U.S. Bur. Min.*, No. 3223, 1934, 19–32. Describes characteristics of explosively crushed products and machine for continuous explosions. Gives efficiency of method.

1593. **Crushing and Grinding.** GROSS, J. *Bull. U.S. Bur. Min.*, 402, 1938, 70–98. Explosive shattering and experimental work on effects of variables on various materials. Tabulated and graphical presentation of results. Illustrated.

1594. **Explosive Shattering as a Possible Economical Method of Ore Preparation.** GROSS, J. and WOOD, C. E. *Rep. Invest. U.S. Bur. Min.*, No. 3268, 1935, 11–19. Gives steam costs, capacity, and efficiency with various amounts of steam.

1595. **Apparatus for and Method of Comminuting a Permeable Material.** INSTITUTE OF GAS TECHNOLOGY, Chicago. *Brit. Pat.* 591921, 1947. The material is passed with superheated steam through a convergent-divergent nozzle, and separation in a cyclone. The object of the invention is to provide a continuous process.

1596. **Method of Explosive Pulverization.** LOBE, W. E., KELLOGG CO. *U.S. Pat.* 2560807, 1951. Coal is first granulated, then formed into a slurry with water; the slurry is pumped to a higher pressure at which the greater part of the water is separated. The pressure is suddenly reduced and explosive pulverization is produced. The steam evolved is recompressed and recycled. Oversize is also recycled.

1597. **Explosion. Unit operation of process industries.** MEIGS, D. *Chem. metall. Engng*, 1941, **48**, 122–5. The application of explosion, i.e. the sudden reduction of pressure surrounding a material previously subjected to a suitable rise of temp. and increase in pressure, by the sudden expansion of the occluded vapour and gas, can be used for the comminution of minerals and cellular materials. Typical processes are the splitting of mica, disintegration of wood chips and the 'puffing' of grain.

1598. **Apparatus for disintegration of solids.** YELLOTT, J. I. *U.S. Pat.* 2515541, 1950. Describes apparatus in which coarse solids are first shattered explosively to form a rapidly flowing gaseous suspension of shattered particles, which are given a vortex movement—this may separate out the finer particles—and the kinetic energy of the suspension is used for further comminution of the larger remaining particles.

1599. **Coal Atomizer.** YELLOTT, J. I. and SINGH, A. D. *Pwr. Plant* (*Engng*), 1945, **49** (12), 82–6. Crushed coal is fed into a pipe containing superheated steam and then released. *See under* Coal.

1600. **Method for Disintegration of Solids.** YELLOTT, J. I. *U.S. Pat.* 2515542, 1950. A method is described for disintegrating a granular fluid-permeable material, in which the material is introduced continuously into a continuous stream of compressed fluid (capable of being expanded with a pressure drop of at least 15 lb/sq. in.), ahead of a discharge point at which the pressure of the granule-suspending fluid is instantaneously reduced.

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Materials

ABRASIVES: DIAMONDS

1601. **B.I.O.S. Reports.** H.M. Stationery Office.

No. 26.	Abrasives. Their Manufacture and Uses in Germany.
No. 113.	The German Abrasive Industry. 70 pp.
No. 459.	The German Coated Abrasives Industry. 15 pp.
No. 1406.	Abrasive Manufacture in Germany. The crushing and sieving processes for the various ingredients are described. Crushing with rolls at 2:1 speed ratio serves to keep the original profile so that regrinding is seldom necessary.

1602. **The German Abrasives Industry.** *F.I.A.T. Final Report*, No. 370. H.M. Stationery Office. 60 pp.

1603. **Study of the Classification of Abrasive Grains such as Corundum and Silicon Carbide.** ANON. *Sprechsaal*, 1954, **87** (19), 473–9; *Verres et Réfr.*, 1955, **9** (1), 51–2. Tables of sizes are presented and simple sedimentation apparatus is described, where a solution of sodium phosphate is used (0·45 g/l. of water). Compressed air is used for obtaining a good mixture. 1 illustration, 1 table.

1604. **The Measurement of Grain Size of Tungsten and Tungsten Carbide Powders used in the Manufacture of Hard Metal.** BURDEN, H. *J. Inst. Met.*, 1948, **75**, 51–68. Various methods are discussed and experimental data presented. Illustrated. 21 refs.

1605. **Diamond Powders.** CUSTERS, J. F. H. *Industr. Diam. Rev.*, 1954, **14**, 147–9. Subsequent to the development of National Standards on diamond powders in England, Germany and the U.S.A., the author has reviewed the problem of specifying sub-sieve diamond powders and makes the following suggestion for a specification, to include (a) the nominal range, (b) the actual range with an upper and a lower limit, (c) undersize which can amount to a maximum of 15% by count, (d) oversize, in which no particles bigger than 1½ times the upper nominal limit should be present, and (e) a cumulative percentage graph, which must nowhere deviate more than 15% from the ideal line.

1606. **A New Diamond Crusher is Described.** FRITSCH, O. *Industr. Diam. Rev.*, 1953, **13** (9), 207. The crusher operates on the principle of a coffee mill, that is by the relatively slow motion of the 'ram' and the 'die'. It splinters the diamond by a milling action instead of by impact crushing. A slight vacuum is maintained to avoid loss and the product is then ground in an iron ball mill to improve the shape of the grains. Size separation is effected in an elutriation vessel attached to the outlet tube.

1607. **Diamond Powder as an Industrial Product.** GRODZINSKI, P. and LEEDS, R. E. *Ber. dtsch. keram. Ges.*, 1953, **30**, 197–204. Paper to 25th Jubilee Conference, Verein Deutsche Ingenieur. Fachausschuss für Staubtechnik. Includes a discussion of the methods of producing diamond powders, e.g. mortar crushing, by hand, by machine, and by ball mills.

1608. **The Hardness of Diamond.** KHRUSCHOV, M. N. and BERKOVICH, E. S. *Industr. Diam. Rev.*, 1951, **11**, 42–9. Method of determining the hardness of very hard materials. Tabular comparisons between boron and tungsten carbides, synthetic corundum and chromium diffused on steel.

1609. **Construction and working of Crushing Plants for Preparing Electrocorundum Abrasives.** PUFFE, F. *Schleif-u. Poliertech.*, 1939, **16**, 107–11; *Ceramic Abstr.*, 1940, **19**, 1.

1610. **Crusher Plates for Diamonds.** YOUNG, R. S. *J. Metals, N.Y.*, 1951, **191** (2), 97. The crushing of 'boart' or low-grade diamonds for industrial applications is an extremely arduous operation. It is crushed in two stages, first by a small jaw crusher and secondly by a roll crusher. The former is the major operation, and martensitic white iron was found to give the best service. Its magnetic properties were useful in enabling a separation of the metallics from the product, and it was possible to crush 1 000 000 carats or 440 lb of industrial diamonds before failure of the martensitic iron jaws.

AGGREGATE

1611. **Single Sized Road Stone Aggregates and Chippings.** *British Standards* 63:1951. A table of grading and particle size, methods of sampling and sieve analysis, determination of flakiness and group classification of rock are given. An appendix gives a short description of each of 90 rocks and minerals.

1612. **Concrete Aggregates from Natural Sources.** *British Standards* 882 and 1201:1954. B.S. 882 gives definitions, quality requirements and sieve gradings for coarse aggregates, fine aggregates and all-in aggregates suitable for use in mixing concrete. Test requirements are given for clay, silt and fine dust, organic impurities and frost resistance. B.S. 1201 provides for coarse aggregate and fine aggregate and all-in aggregate suitable for preparation of concrete floor finishes.

1613. **Grading Requirements for Gravel.** *British Standards* 1984:1953.

1614. **18 Specifications and 33 Methods of Test for Aggregates for Road Construction and Concrete.** *A.S.T.M. Stand.*, Part 3, 1955.

1615. **Rock Crusher Performance.** ANON. *Chem. and Process Engng*, 1953, **34** (10), 331. A note on the 'Gyrasphere Crusher' made by Pegson, Ltd., on the principle of an inverted pestle and mortar. It was found by J. W. Swindells, Ltd., New Mills, near Buxton, Derbyshire, to avoid the excessive wear previously experienced in reducing high silica rock to road aggregate. The new crusher gave a cubical product, minimum of dust, and could take unlimited feed. Sizes 24, 36 and 48 in.

1616. **Making Cubical Chippings.** *Edg. Allen News*, April, 1955, **34** (394), 80–1. The Edgar Allen Stag K.B. granulator is described and illustrated. A cubical shape is obtained by virtue of design of liners, and adjustable breaker plate. The heavy steel rotor is provided with three adjustable swing hammers. Four sizes are made and performance figures for various rocks are tabulated. **[P]**

1617. **The Kessler Fairleede Double Impeller Breaker.** *Min. J.*, 7 Mar. 1952, 246. A new type of impeller breaker giving a 20:1 ratio. Claimed to be the first really new method of stone and gravel reduction for over 30 years. The material fed to the crusher falls on to the impellers revolving at 1200 rev/min. Three bars in each impeller provide the first impact, throwing the fragments on to the breaker, colliding with each other and with new material entering the breaker, producing a clean cubical product with a low percentage of dust.

1618. **Stone Crushers.** ANON. *Mine & Quarry Engng*, 1943, **8**, 123. An illustrated account is given of stone crushers and crushing rolls. The ratio of reduction, defined as the ratio between the maximum dimension of the fragments at the entry of the crusher and their maximum dimensions at the outlet, and the physical limit to the reduction ratio, imposed as a result of the failure of the material to slip between the crushing surfaces are discussed. The comparison between the greater capacity of gyratory crushers and the capacity of jaw crushers, together with the comparison between grades of product are tabulated.

1619. **Crushing Plant Prepares Garfield Slag for Railroad Ballast.** ANON. *Min. Engng, N.Y.*, 1953, **5** (7), 661. A jaw crusher and cone crusher give the desired size

reduction and minimize the production of fines. Dust is avoided by wetting prior to crushing.

1620. **Gradation of Crushed Material and the Problem of Cubic Material.** ANON. *Pierres et Min.*, 1934, **6** (61–2), 959–70, 980–1; *Road Abstr.*, 1935, **2**, 125. Present-day demand is for 'cubical' stone. The content of flaky particles in crushed stone is primarily dependent on the nature of the stone, but is also largely affected by the form of the crushing surface, particularly in the neighbourhood of the discharge opening. A grooved surface yields more regular material, both as regards shape and size, than a plane surface. Surfaces may be placed in the following descending order of effectiveness: indented, curved (gyratories); indented, rectilinear (jaw crushers, crushing rolls); smooth, slight curvature (gyratory granulators); smooth, large curvature (cone crushers); smooth, rectilinear (crushing rolls and disc crushers). The first in the list cannot be used under practical conditions. Another factor governing shape is the type of feed. Heavy or forced feeding causes intense friction and the breaking of particles one against the other. The weaker, flaky or spiky particles are largely eliminated. One quarry producing porphyry, for example, passes the whole of the material from a cone crusher through an old jaw crusher with diagonal indentation of the jaw-plates, at full speed, solely to break up the flaky particles by abrasion.

1621. **Analysing Crushed Stone Production.** ANON. *Rock. Prod.*, 1945, **48** (8), 82. Formulae are presented for the determination of the capability of equipment in producing a given size of aggregate, or changes in methods to produce a required tonnage of that product. It is shown that the amounts in tons per hour and the complete sieve analyses of the primary and secondary circuits must be known, the upper limit of the desired product, and the size and quantity of a secondary product if wanted.

1622. **Large Plants for Aggregate Production.** ANDERSON, M. P. *Civ. Engng, Easton, Pa.*, 1939, **9** (6), 341–4. Production of aggregate at low cost is dependent to a large extent on the selection of machinery capable of producing material continuously and at a high rate. Experience obtained with aggregate plant in the construction of three large concrete dams in America shows the advantage of using robust plant of ample capacity. Modern aggregate plant makes extensive use of belt conveyors and interlocking electrical controls. Few changes have been made in the design of crushers. At the Norris Dam satisfactory results were obtained from the use of a cone crusher for secondary crushing, this machine being capable of grinding more finely than a gyratory crusher, whilst the size of the product can be varied. Multi-deck vibrating screens are replacing those of the revolving type on account of their higher efficiency, economy and compactness. Increasing use is being made of the hydraulic method for the separation of sand sizes.

1623. **Some Results of Research Work on Jaw Crushers.** BAUMANN, V. A. *Mech. Constr., Moscow* (*Mekhan. Stroit.*), 1954, **11** (7). A translation may be consulted at D.S.I.R. Ref., Records Section, 22988. *See under* Jaw Crushers. [P]

1624. **Aggregate Analysis as an Aid in the Study of Soil Structure Relationships.** BAVER, L. D. and ROADES, H. F. *J. Amer. Soc. Agron.*, 1932, **24**, 920–30.

1625. **Practical Results of Crusher Investigations.** BERDEL, L. *Hoch- u. Tiefb.*, 1937 (42). Investigation into the particle shape of 12 000 particles of crushed hardstone; the products from new and worn crusher jaws are compared. 30 tons each of two different hard siliceous limestones were crushed at about 3-in. setting. Effect of rock type, and moisture content were studied. [P]

1626. **The Preparation of Coarse Aggregate.** BERGEAUD — (La Fabrication du Gravillon). *Revue gén. Routes*, 1934 (9), 291. Effect of feed and operating conditions, with particular reference to aggregate production.

1627. **Method and Apparatus for Crushing Rock.** BLAND, J. *U.S. Pat.* 2468321, 1949.

This patent describes a method of, and apparatus for, simultaneous impact crushing of separate streams of sized rock.

1628. **Evolution dans la Technique du Gravillon.** Bonjean, R. *Sci. et Industr. La Route*, 1938 (65 bis) (Special number), 5–10; *Road Abstr.*, 1938–9, **5**, 338. A survey of the factors in the production of high-quality aggregate, with particular reference to operating conditions and the development of granulators.

1629. **The Classification and Mechanical Testing of Road Making Aggregates. A critical Comparison of British and German Practice.** Breyer, F. G. *Strasse u. Autobahn*, 1950, **1** (12), 25–9. The German methods of test referred to are based on DIN 52108–9 and the British on work carried out by F. A. Shergold at the D.S.I.R. Road Research Laboratory, Harmondsworth.

1630. **Crushing: A Discussion of the Value of Different Types of Stone Crushers.** Brown, G. J., Holt, F. W. and Armitage, E. *Quarry Mgrs' J.*, 1933, **16** (12), 394–401. Comparison of gyratory, impact, jaw and roller crushers.

1631. **New Approach. Reliable Method of Aggregate Gradation Control is in Use.** Cornelius, M. E. *Calif. Highw.*, 1951, **30** (3/4), 21–4. Methods of controlling the grading of plant-mixed aggregate are reviewed. A new method of sampling the aggregate in a continuous asphalt mixing plant is described and illustrated.

1632. **Measurement of Apparent Density of Aggregates.** Destable, F. *Ann. Inst. Bâtim.*, 1951, No. 168. Methods and accuracy of measurement are discussed. 15 pp.

1633. **Development of the Stone Breaker.** Dickenson, H. W. *Cement Lime & Grav.*, 1945, **20** (9), 78–83. Deals with jaw, gyratory and roller crushers.

1634. **Balancing Equipment in Crushed Stone Quarries.** Farrell, W. E. *Rock Prod.*, May 1934, **37**, 34–8. An investigation into the output of three quarries and into the efficiencies of the primary crushers (jaw and gyratory). Shovels and transportation performances are included, much data is given and presented graphically. [P]

1635. **On the Attrition Resistance of Broken Stone.** Gerth, G. *Steinindustrie*, 1935, **30**, 385; *Road Abstr.*, 1936, **3**, 88. 5-cm stones are tested in a 20-in. rotating drum and the fine material weighed periodically.

1636. **A Large Stone Crushing Plant.** Gorbatov, N. A. *Mech. Constr., Moscow* (*Mekhan. Stroit.*), 1951, **8** (2), 16–9. Details and operation of a plant to produce 674 000 cubic metres per annum in sizes ranging from 16 in. downwards, using 450-kW engine.

1637. **Stone Crushing on the Volga–Don Construction Project.** Gorkov, A. V. *Min. J., Spb.* (*Gornyi Zhurnal*), 1952 (9), 27–37. General layout of the whole plant is described.

1638. **Hardstone Crushing Experiences.** Hawkar, P. *Pierres et Min.*, 1935, **7** (74), 1156-61; *Quarry Mgrs' J.*, 1935 **18** (4), 143–8. Observations on jaw, gyratory and cone crushers, based largely on experience at the Quenast Quarries.

1639. **Practical Aspects of Noise Control in Crushed Stone Plant.** Hoftizer, A. B. *Pit & Quarry*, 1955, **47** (11), 76–7, 82. *See under* Noise Control.

1640. **The Application of Double Impeller Breakers in the Minerals Industry. I.** Lehmann, H., Buchartowski, H. G. and Parpart, J. *TonindustrZtg*, 1951, **75**, 372–7. A very thorough investigation is reported on this type of hammer mill, used in the preparation of concrete aggregates. The machine is said to be highly efficient. [P]

1641. **The Application of Double Impeller Breakers in the Mineral Industry. II.** Lehmann, H., Meffert, H. and Buchartowski, H. G. *TonindustrZtg*, 1952, **76**, 9–14. A survey of the possible uses of this type of hammer mill in the mineral industry. It is suitable for crushing road stone or aggregates, raw and calcined lime and clinker,

and for preparation of grog and slaty clays. A tabular and graphic presentation of technical data from 12 types of prall mill for various rocks and for clinker is given. [P]

1642. **Crushing Plant Set-up for Many Sizes at St. Paul Quarries, Inc.** LENHART, W. B. *Rock Prod.*, Oct. 1953, **56**, 105–6. Processing for high calcium chemical and metallurgical stone which meets all specifications for commercial aggregates and agricultural stone (agstone). Illustrations, flow sheet.

1643. **Improvements Relating to the Structure of a Solids Disintegrating Machine Facilitating Operation and Maintenance.** LUKENS STEEL CO., Coatesville, Pa. *Brit. Pat.* 713490, 713491, 1952/54. The patents refer to a mobile mechanism suitable for operation from a tractor or similar engine, and having arrangements for feeding from the ground to the impact mechanism and particularly arrangements for replacing worn parts.

1644. **The Shape of Road Aggregate and its Measurement.** MARKWICK, A. H. D. *Bull. Rd. Res. Bd.*, No. 2, 1936, H.M. Stationery Office; *Road Abstr.*, 1936, **3**, 620. References to work carried out at the D.S.I.R. Road Research Laboratory, mainly on the effect of rock type on the grading and shape of the product of a small jaw crusher.

1645. **Some Problems in the Control of Road Materials.** MARKWICK, A. H. D., LEE, A. R. and GLANVILLE, W. H. *Chem. & Ind.* (*Rev.*), 1939, **58** (7), 131–43; *Road Abstr.*, 1939, **6**, 233.

1646. **The Grading and Shape of Commercial Sizes of Aggregates.** MARKWICK, A. H. D. *J. Soc. Chem. Ind., Lond.*, 1941, **61**, 85–91; *Road Abstr.*, 1942, **9**, 361.

1647. **The Preparation and Grading of Concrete Aggregates.** MILLER, W. T. W. *Civ. Engng, Lond.*, May 1932, 33.

1648. **The Evaluation of Various Types of Crusher for Stone and Ore and the Characteristics of Rocks as Affecting Abrasion in Crushing Machinery.** MILLER, W. T. W. and SARJANT, R. J. *Trans. ceram. Soc.*, 1936, **35** (11), 492–550, 554–60; *Road Abstr.*, 1936, **3**, 622. *See* Nos. 761–2.

1649. **Development in Impact Crushing in the U.S.A.** MITTAG, C. *Z. Ver. dtsch Ing.*, 1952, **94** (13), 365–7. It has had extremely wide application in road building.

1650. **Machine for Breaking Stone, etc., by Means of Impact.** POYSER, R. G., MARSDEN, H. R., LTD. *U.S. Pat.* 2705596, 1955. A pair of four-hammer shafts revolve towards each other. The stone falls vertically in two streams, is struck by the hammers and projected to the casing. Less wear is claimed.

1651. **Self-propelled Crushers.** RIEDIG, F. *Strasse- u. Tiefb.*, 1949, **1** (1/2), 30–1. Descriptions are given of the design, operation and capacity of two types of self-propelled German plant for crushing and screening aggregates. The stone fed to the crusher may be up to 3 in. across.

1652. **An Investigation of Crushers, with Special Reference to Particle Shape.** ROSSLEIN, D. *Quarry Mgrs' J.*, 1947, **30** (4), 207–22. An abridged translation by F. A. Shergold of the Road Research Laboratory, D.S.I.R., of the author's paper appearing in *ForschArb. StrWes.*, 1941, **32** (Volk und Reich Verlag.). From an investigation of the relations between the material to be crushed, the crusher, and the product, carried out at the Forschungsinstitut für Maschinenwesen beim Baubetrieb (Institute for research in mechanical engineering as applied to constructional work), the following facts were established. A fixed relation depending upon the type of crusher, exists between the particle size produced in the highest proportion by weight and the minimum width of outlet of the crusher. A relation also exists between the maximum particle size in the product and the maximum width of outlet. The proportion of cubical particles varies with the absolute width of the particles, but the main factor determining

the number of cubical particles is the type of stone used. Badly-worn crusher jaws affect the quality of the product. It is recommended that the width of outlet of a crusher should be defined as the distance between the teeth in one jaw and the gaps in the other, and that minimum and maximum widths should be stated for any crusher that has been in use previously. [P]

1653. **Evaluation of the Various Granular Forms of Broken Stone and Laminar Split.** ROTFUCHS, G. *Zement*, 1931, **20**, 660. The basis of the evaluation for particular uses is the number of pieces per litre according to size. Tabular and graphic representation of data.

1654. **Factors Governing the Grading and Shape of Crushed Rock.** SHERGOLD, F. A. GREYSMITH, M. G. *Quarry Mgrs' J.* 1947, **30** (12), 703–10. A survey of the literature carried out at the Road Research Laboratory, Harmondsworth, suggests that it is possible to produce aggregates of a reasonably good particle shape, and in a wide variety of gradings, from any of the rocks commonly used as road stone, using any of the types of crusher in current use for producing road aggregates. The operating conditions are the most important factor. Conditions that favour the production of good cubical aggregate are: (1) a low reduction ratio, especially in the final stage of crushing; (2) the removal, by scalping, of chippings and fines formed in primary crushing, so that they are not included with the finished products; (3) choke feeding; (4) closed-circuit feeding; (5) the use of corrugated crushing surfaces, which should be discarded when the corrugations are badly worn.

1655. **Abstract Summary of Monograph by A. Bonwetsch, 1933.** SHERGOLD, F. A., *Quarry Mgrs' J.*, 1946/7, **30** (10), 586–97. *See under* Jaw Crushers. The original contained a mathematical analysis of the operation of jaw crushers and an account of the associated experimental work illustrated by over 100 tables, graphs, wattmeter diagrams and oscillograph records. [P]

1656. **Researches on Stone Crushing with Particular Regard to the Shape of the Product.** SHERGOLD, F. A. *Quarry Mgrs' J.*, 1947, **30** (4), 207–22. Abridged translation of monograph by D. Rosslein, 1941. The monograph includes a brief review of previous work and describes an extensive investigation carried out at seven quarries to determine to what extent the conditions and rock type affect the grading and shape of crushed stone used as road aggregate and to study power consumption and production costs with a view to economy. The work of Bonwetsch, the Swedish State Road Research Institute, Bendel and Rosin and Rammler are quoted. *See under* Rosslein. [P]

1657. **Research on Jaw Granulators.** SHERGOLD, F. A., *Bull. Ass. int. Route*, 138, 1954. *See under* Jaw Crushers.

1658. **A Study of Single Sized Gravel Aggregates for Road Making.** SHERGOLD, F. A. *Tech. Pap. Rd. Res. Bd.*, No. 30, H.M. Stationery Office, 1954. A compilation of data from a recent survey of gravel production in which a wide range of tests was made on 300 samples from 70 different sources. Notes on distribution, classification and methods of production are presented. The grading requirements in B.S. 1984: 1953, are given. [P]

1659. **Results of Tests on Single-sized Roadmaking Aggregates.** SHERGOLD, F. A. *Quarry Mgrs' J.*, 1955, **38** (10), 636–42. The note summarizes the results of tests for grading, shape, water absorption, specific gravity and resistance to crushing, impact and abrasion made on 244 samples of single-sized aggregates, supplied by 45 county surveyors in England and Wales from aggregates delivered to them in 1953. The main object was to compare the grading and shape of the samples with the requirements laid down in B.S. 63:1951. [P]

1660. **Research on Road Stone Aggregate at the Road Research Laboratory.** SHERGOLD, F. A. *Quarry Mgrs' J.*, 1955, **39** (6), 346–60. A summary of the research plant facilities at the D.S.I.R. Road Research Laboratory.

1661. **Investigation of Stone Crushers.** STATENS VAGINSTITUT (Swedish State Road Research Institute). *Meddelande*, No. 55, Stockholm, 1937. Extensive investigations carried out on 5 jaw-crushers, 1 disc crusher and 3 impact crushers using various types of rock. Results given for grading and energy consumption, capacity and power consumption. [P]

1662. **Road Research Laboratory (D.S.I.R.) Experimental Crushing Plant.** TAYLOR, F. G. *Engineering, Lond.*, 1953, **175** (4570), 281–3. A plant has been erected to permit full-scale investigation of the effect of variations in feed and operating conditions of crushers on the grading and shape of the aggregates produced.* In addition to feeder and vibrating screen, facilities have been provided to test a representative range of types of crusher, including jaw granulators, impact breakers, cone crushers and crushing rolls. The size of crusher is necessarily limited to about 30 tons per hour. The stone is tested for grading and particle shape before and after crushing. [P]

1663. **A Survey of Some Mixing Plants for Asphalt and Coated Macadam.** WATERS, D. B. *Tech. Pap. Rd. Res. Bd.*, No. 30, H.M. Stationery Office, 1953. The first half of the report dealt with the crushing and proportioning of the aggregate. Tabular and graphically reported data are given for sample efficiency, gradings of crusher output, variation in grading in stockpiles and in hot storage bins. The screening system is described and investigated. 47 pp.

1664. **Gap Graded Aggregates in Vibrated Concrete. Fundamental Studies of Relationships Governing Particle Interference.** WILLIAMS, J. E. H. *Engineer, Lond.*, 1955, **179** (4662), 693–8. A concrete aggregate is said to be gap-graded if one or more of the recognized standard size groups is absent. The gap may occur naturally or may be produced deliberately by suitable screening. The benefit of such grading is recognized to be due to reduction in wedging action by the intermediate gradings. The phenomenon of particle interference is analysed and the establishment of the principle governing the action of gap graded aggregates in vibrated concrete is discussed. The subject is fully illustrated by diagrams, photos., graphs, 6 refs.

ASBESTOS

1665. **Asbestos Milling.** *Miner. Inf. Serv. Calif.*, 1951, **4** (6), 1. The milling of asbestos consists of separating the fibre from the barren rock by repetitive crushing, screening and air separation. A typical mill flow sheet includes primary and secondary crushing to 3-in. size, furnace drying to remove moisture, and third-stage crushing to free the fibre. The third-stage crushed product is then screened and the fines are disintegrated to fluff the fibres.

1666. **Apparatus for Milling Asbestos Cobs and Like Fibrous Ore Bodies.** ANDERSON, N. I., Johannesburg. *U.S. Pat.* 2694530, 1951/54. The normal method is to break in a jaw crusher and then pass through a hammer mill. In the present apparatus, the feed passes down a rapidly rotating vertical tube and is thrown out through the lower horizontal portion of the tube against a breaker ring. There is only one impact and the fibres are carried upwards and out by an upward air stream and the heavy material falls to a lower outlet. The whole is encased. The single impact preserves the original fibres better.

1667. **Improvements in or Relating to the Milling of Asbestos and the Like Fibrous Ore Bodies.** ASBESTOS EXTRACTION AND MACHINERY (PROPRIETARY), LTD., S. Africa. *Brit. Pat.* 705998, 1952/54. The patent relates to the removal of grit and heavy particles from the comminutor, e.g. hammer mill. A cylindrical screen revolves in a chamber into which the product is drawn by suction and adheres to the screen as arranged by guides. The heavy particles do not adhere but fall to an outlet and so are separated.

* Quarries sometimes have difficulty in meeting specification requirements, particularly for bituminous road surface aggregate.

The desired fibre adhering to the screen is removed later in the revolution. The device is in effect a rotary suction filter for the light particles.

1668. **The Preparation and Grading of Chrysotile Asbestos in Canada.** JENKINS, G. F. (Asbestos Corporation, Thetford Mines, Quebec.) Institute of Mining and Metallurgy, Symposium on Mineral Dressing, London, Sept. 1952. Paper No. 39, 13 pp. The rock circuit is: jaw crusher, 42 × 36 in.; crushing rolls or gyratory crusher, 100 h.p.; hammer crusher, 100 h.p.; dryers, etc.; data on output. Tests on the free fall drum type mill are described in detail. Development and early flow sheets are included. Published in *Recent Developments in Mineral Dressing*, Institution of Mining and Metallurgy, 1953. [P]

1669. **Application of Air to Asbestos Milling at the New Jeffry Mill of the Canadian Johns-Mansville Co., Ltd., Asbestos, Quebec.** ROSOVSKY, H. *Trans. Canad. Min. Inst.* (*Inst. Min. Metall.*), 1955, **58**, 268–77. The handling of 14 000 tons of ore per day requires about 2·5 million cu. ft/min of air or about 10 tons of air for each ton of ore mined. The system is an automatically controlled pressure-volume one and filtered air is returned or rejected. The multiplicity of systems is described.

CARBON: GRAPHITE

1670. **Permeability Studies. Surface Area Measurements of Carbon Blacks.** ARNELL, J. C. and HENNEBERRY, G. O. *Canad. J. Res.*, 1948, **26A** (2), 29–38.

1671. **The Reduction of the Crystalline Perfection of Graphite by Grinding.** BACON, G. E. *Acta cryst., Camb.*, 1952, **5** (3), 392.

1672. **Attempt to Produce Carbon Black by Fine Grinding.** BREMNER, J. G. M. and COLPITT, J. H. *I.R.I. Trans.*, 1948, **24**, 35–51. The authors used the tinting strength test to assess the mean size of ground materials, using Thermax, 274 micro-mu (rubber black), as their standard. This test is considered satisfactory for the range 100–1000 micro-mu.

1673. **Shape Factor and Other Fundamental Properties of Carbon Black.** COHAN, L. H. and WATSON, J. H. L. *Rubb. Age, N.Y.*, 1951, **68**, 687–98. Discusses and illustrates the particle size, surface area and shape of carbon blacks.

1674. **Crushing Strength of Carbon Black Beads.** COLUMBIAN CARBON CO. *Chem. Engng News*, 1954, **32** (43), 4287. A special analytical balance is used.

1675. **Determination of Surface Area of Carbon Blacks.** FUNK, R. and RAMMELE, F. *Chem. Tech., Berlin*, 1954, **6**, 213–21; *Chem. Abstr.*, 1954, **48**, 9784.

1676. **Recent Researches on Indian Graphite.** MAJUMDAR, K. K. *Indian Min.*, 1950, **4** (1), 19–21. The preparation of Indian graphite is described. It is converted to colloidal state by repeated grinding in a roller mill admixed with mineral oil, and a solution of rubber in benzene as a protective colloïd (and lecithin). Or it can be emulsified in water by using soap. Before grinding, Indian graphite was purified to 99% C by flotation. 19 refs.

1677. **Some Mechanical Properties of Graphite at Elevated Temperatures.** MELMSTROM, C., KEER, R. and GREEN, L. *J. appl. Phys.*, 1951, **22** (5), 593. Experiments show that for several grades of graphite, the tensile strength assumes a maximum at about 2500°C, which was 40% higher than at room temperatures.

1678. **Developments in the Dispersion of Carbon Black.** VENUTO, L. J. *Off. Dig. Fed. Paint. Varn. Prod. Cl.*, Mar. 1940, 159–73. This presents an excellent example of the results that can be obtained from a careful study of grinding formulae of the paint. A detailed investigation into aspects governing dispersion. Results are tabulated and presented graphically.

1679. **Further Electron Microscope Studies on Colloidal Carbon and the Role of Surface in Rubber Reinforcement.** WIEGAND, W. B. *India Rubb. World*, 1941, **105**,

270–2. The determination of the mean sizes of different carbon blacks with the electron microscope is described and the surface area in area per pound is estimated. The influence of size and surface in rubber compounding is described.

CEMENT

1680. **Grinding Raw Materials for Cement Manufacture.** *See also under* Grinding Aids.

1681. **Portland Cement. (Ordinary and Rapid Hardening.)** *British Standard* 12:1947. Composition and manufacture. Tests for fineness, chemical composition, strength, setting time and soundness.

1682. **Low Heat Portland Cement.** *British Standard* 1370:1947. An appendix describes the apparatus and method for determining the fineness of the cement by means of a permeability test (the Lee-Nurse method).

1683. **Standard Methods for Testing Cement.** *Book of A.S.T.M. Standards.* 1955, Pt. 3. Standard Method of Test for Fineness of Hydraulic Cement. A.S.T.M. Design C. 184–44, pp. 142–4. Standard Method of Test for Fineness of Portland Cement by Air Permeability Method. A.S.T.M. Design C. 209–55, pp. 145–51. Standard Method of Test for Fineness of Portland Cement by Turbidimeter. A.S.T.M. Design C. 115–53, pp. 152–60.

1684. **Aggregate.** *Book of A.S.T.M. Standards,* 1955, Pt. 3. 18 Specifications and 33 Methods of Test for Aggregates for Road Construction and Concrete.

1685. **Ore Dressing and Cement Machinery in Germany, 1939–1945.** *B.I.O.S. Final Report,* No. 1753, 1947, H.M. Stationery Office.

1686. **The German Portland Cement Industry.** *F.I.A.T. Final Report,* No. 519, Nov. 1945, H.M. Stationery Office. Pt 1. Among the usual hammer mills for crushing the quarry stone, there were observed ingenious feeders for the hammer mills. Some details of a dry grinding ball mill with air separator of a novel character (two cone separator), a slotted ball mill and edge-runner mill are given. Pt 2. Raw materials grinding by the (1) Loesche Mill (in England known as the Lopulco Mill, by International Combustion Products, Ltd.)—by rollers on rotating table with variable pressure; (2) air-swept mill, by Humboldt-Motoren A.G.—a ball mill to which coarse material is returned by a double cone separator; (3) the Pfeiffer Mill—a ball mill slotted in the middle for exit of fines, coarse material is separated and returned by a cone separator. Performance data are given in full as well as ball load and sizes, etc. [P]

1687. **Exploitation of Low Grade Ores in U.S.A. Chap. IV. Vibrating Ball Mill.** *O.E.E.C. Technical Assistance Mission,* No. 228, 1954. O.E.E.C., Paris. Obtainable from H.M. Stationery Office. A 42 × 42-in. mill had been installed for grinding cement clinker. It is stated to have about seven times the capacity of a conventional ball mill of the same size.

1688. **A Post-War Grinding Mill.** ANON. *Cement & Lime Manuf.,* 1949, **22,** 85; 1950, **23,** 868. A new clinker-grinding mill is described; it has produced over 200 000 tons in just under two years, and its performance is stated to be high. It is a compound mill 40 ft long, 7 ft 6 in. diameter inside the shell, and is fitted with a trunnion feed and discharge. 15 figs.

1689. **Mills for Clinker Grinding.** ANON. *Cement & Lime Manuf.,* 1945, **18,** 1–7. The development of clinker grinding technique is reviewed.

1690. **New Portland Cement Process.** ANON. *Chem. Engng,* 1953, **60** (5), 384; *U.S. Pat.,* 2627399, 1953. Portland cement can now be made below the sintering point, after pelleting with water and pressing at 10 tons/sq. in. The pellets are fed to a vertical drying and reaction chamber countercurrent to air flow.

1691. **Grinding of Cement Clinker and Lime-clay to Produce New Cements.** ANON. *Concrete, N.Y.*, 1933, **41**, 27–30. The heat evolution (H) in the hydration of rapid-hardening Portland cements (I) is due chiefly to the $3CaO, SiO_2$ content. A new (I) with a low (H) is described. Quicklime and moist lump clay are ground together and hydrated. The product is finely ground with Portland cement clinker under controlled conditions. Higher mortar compression strengths than those of a standard (I) are claimed.

1692. **Heavy Crushing Plant for Cement.** ANON. *Crush. & Grind.*, 1931, **1**, 37. A description is given of the grinding machinery at the works of G. & T. Earle, Ltd., Hope, Derbyshire.

1693. **Sulphuric Acid Plant. Anhydrite Process.** ANON. *Engineering, Lond.*, 12 Nov. 1954, 640–1. At the Widnes plant the anhydrite is crushed by two Symons crushers driven by 75-h.p. motors. Sand, shale and coke are dried in two Head Wrightson rotary driers after being broken by hammer mills. Dryers are oil fired with flame detectors. One dryer for sand and shale, the other for coke. The ingredients are then mixed and ground in a ball mill driven by a 900-h.p. synchronous motor. The clinker from the furnace is passed over shaker conveyors to jaw crushers and then to the clinker store. Then it is weighed, 5% gypsum added and passed to a four compartment grinding mill driven by a 1200-h.p. B.T.H. synchronous motor through a double helical gear. Dust cyclones are used.

1694. **Kiln Plants and Milling Machines for the Cement Industry.** *Escher Wyss News*, 1948–9, **21**, **22**. Includes a description and drawing of the four-chamber compound mill for raw material and clinker. It is of welded construction, annealed for stress relieving. The first and second chambers are lined with hard steel plate, and the third and fourth chambers with siliceous stones.

1695. **Closed-circuit Finish Grinding, Unit-firing System serve Lawrence Plant at Siegfried.** ANON. *Pit & Quarry*, 1941, **34** (5), 52–3; *Ceram. Abstr.*, 1944, **5**. The installation of direct-firing coal mills on some of the kilns of the Lawrence Portland Cement Co. at Siegfried, Pa., is discussed.

1696. **1. Bibliography on Viscosity of, and Workability Aids for, Cement Pastes. 2. Bibliography on Grinding and Grinding Mills.** ANON. *Rev. Matér. Constr., C.*, 1953 (459), 347–52; *Build. Sci. Abstr.*, July 1954, 963F. Over 50 international references to the literature of crushing, grinding, crushers, grinding mills, etc., with special reference to the manufacture of cement.

1697. **Symposium on Cement Crushing.** *Rock Prod.*, 1931–2, **34** and **35**. These volumes contain reports of the work carried out before 1926 under the auspices of the Joint Research Committee of the British Cement Manufacturers.

1698. **Grinding Without Balls.** ANON. *Rock Prod.*, 1942, **45**, 25, *Build. Sci. Abstr.*, 1942, **15**, 181. In view of the possibility of saving 30 000 tons of iron per year it is shown diagrammatically how to finish ground Portland cement with the clinker itself as the grinding media instead of using iron.

1699. **From Open to Closed Circuit Grinding with Liquid Cyclones.** ANON. *Rock Prod.*, 1953, **56** (7), 62–6. The installation by the S.W. Portland Cement Co., is one of the first of such classifiers. The plant and equipment are illustrated and a considerable amount of performance data is presented. An increase of 30% in raw mill grinding is claimed since the installation of liquid cyclones. [P]

1700. **Raw Materials for Cement.** ANON. *Times Review of Industry*, 1951, **5** (55), 12. Describes methods of winning, crushing and grinding, slurrying and conveying to the kiln, the limestone, chalk and clay used in the manufacture of cement.

1701. **The Particle Size of Cement.** AICHINGER, K. and JORDAN, A. *Zement-Kalk-Gips.*, 1953, **6** (12), 451–7. An experimental investigation into the relation of particle

size of cement to its behaviour in use. Relations between specific surface, particle size and time of milling are presented in block and tabular form. It was found that the strength of concrete rises with increasing specific surface, that certain rapid setting cements could be coarser, the setting time being hastened by increasing fineness. Very fine cements therefore require a larger addition of gypsum. There is an optimum fineness for maximum strength. Below this, therefore, strength will be lost. It is concluded that rapid grinding can be accomplished only with a graded feed of maximum size, 10 mm. As a measure of fineness, specific surface should be decisive and not sieve grading. (*See* Huttig, *Radex Rdsch.*, 1953 (11), for the opposite view.) Graphs and histograms are presented to support the relation between surface and strength. Of 33 countries, 26 specify sieving as the criterion of fineness. The author employed the permeability and nephelometric methods. 15 refs.

1702. **Effect of Size of Grinding Media on Properties of Cement.** ANDEREGG, F. O. *Cement & Lime Manuf.*, 1945, **18**, 12–3. Experiments were made in a mill (12×10 in. diameter, 40 rev/min.; balls $\frac{7}{8}$ and $\frac{3}{8}$ in. diameter) charged with 100 lb of balls and 10 lb of clinker. The clinker, which contained lumps up to 0·25 in. diameter, was ground with difficulty when the smaller balls were used, but the workability and H_2O-retention of the resultant cement were better than that of cement ground with large balls only. Grinding with the two sizes of balls gave a higher mortar strength. Certain humps were noticed in the particle-size distribution curves, but the evidence was insufficient to indicate their cause or method of elimination.

1703. **Apparatus for Size Estimation of Cement, for Industrial Use, and some Investigations with it.** ANDREASEN, A. H. M. and LUNDBERG, J. J. V. *Zement*, 1930, **19**, 698–701, 725–27. Results of determinations are presented in tabular and graph form for various cement materials, with and without addition of peptizers.

1704. **Cement Production.** ANSELM, W. 1911, Zement Verlag, Berlin.

1705. **Open or Closed Circuit Mills for the Grinding of Cement.** ANSELM, W. *TonindustrZtg*, 1950, **74** (11), 2267. A comparative analysis was carried out between cements ground with open-circuit and closed-circuit mills. Grading diagrams for both types are plotted by the methods of Bennett and Rammler. The author also confirms the Rosin–Rammler equation. His own contribution is the formula:

$$\text{Surface} = \frac{36{\cdot}8 \times 10^4 \times f}{\mu a \times n \times y} \text{ (sq. cm/g)}$$

where f=shape factor (1·75 for cement), μa=average grain size (cm), n=shape of the grain size distribution curve, and y=sp. gr. of the material. This equation, together with the diagrams shown, can be used for calculating the specific surface of cement. An investigation by A. R. Steinherz on the structure surface and hardness of seven Portland cements is explained. Some comments are made on the B.S. specification for Portland cement, but they appear to be based on an early edition of the specification. A comparison between cements ground in open and closed circuits, with regard to specific surface and hardness, is only possible when the raw materials, chemical composition and calcining treatment are exactly alike. When such comparisons were made, the compound open-circuit ground cements proved always superior, especially when very finely ground; the compound mill is also more economical. Where the uniformity of the grains is important, the closed circuit mill is the better; this is shown by the grading diagram. A table shows the surface values which can be obtained, measured by Wagner's turbidimeter, by the permeability method and according to the author's formula. 2 figs., 1 table. [P]

1706. **Dust Removal, Grinding Technique, Vertical and Rotary Cement Kilns.** ANSELM, W. 1952, Instituto Tecnico de la Construcion del Cemento, Madrid. A long abstract, in German, in *Zement-Kalk-Gips.*, 1953, **6** (4), 131.

1707. **Fine Grinding in Ball Mills.** BEKE, B. *Epitponyag*, 1950, **2** (5/6), 84–8; *Hun-*

garian Technical Abstracts,1951, (3), 14. The use and operation of ball mills in the manufacture of Portland cement are described. The method of preparing milling diagrams is shown.

1708. **Tube Mills in the Cement Industry.** BIRTHELMER, L. *Silikat Technik*, 1954, **5**, 163. The operation of tube mills for cement, the feeding of grinding media and their wear, are described in detail.

1709. **Cement, Lime and Plaster.** BLANC, M. E. C. *Rev. Matér. Constr.*, 1924, **174**, 57–60. Calculating the horse-power consumed in (cement) ball mills. An empirical formula has been developed whereby the motive power necessary for rotating a ball mill is determined from its dimensions, the wt. of the charge and a filling coeff., dependent upon the vol. occupied by the charge. The formula is $F=CT\sqrt{D}$, where F is the motive power in horse-power, T the total wt. of pebbles, D the interior diameter of the mill, C the filling coeff., which depends upon the kind of pebbles (grinding medium) used, and also upon the filling ratio (ratio of vol. of charge to total (inside) vol. of mill). For cement grinding the values of C are:

Grinding medium (filling ratio)	0·1	0·2	0·3	0·4	0·5
Flint pebbles	13·3	12·25	11	9·5	7·8
Steel balls (large) for initial grinding	11·9	11	9·9	8·5	7
Steel balls (small) for final grinding	11·5	10·6	9·5	8·2	6·8

Example: Mill with 3 compartments. Diameter 1·65 m, length 8·2 m, internal diameter 1·565 m, rev/min 25; 1st compartment (1), length 2·775 m, 6 tons large steel balls, filling ratio 0·2; 2nd compartment (2), length 3·50 m, 4 ton flint pebbles, filling ratio 0·37; 3rd compartment (3), length 1·50 m, 6 tons small steel balls, filling ratio 0·45. The horsepower is calculated for each compartment separately:

$$F_1=11\times 6\times \sqrt{1\cdot 565}+10\%=91 \text{ h.p.}$$
$$F_2=9\cdot 95\times 4\times \sqrt{1\cdot 565} =50 \text{ h.p.}$$
$$F_3=7\cdot 6\times 6\times \sqrt{1\cdot 565} =57 \text{ h.p.}$$
$$\overline{198 \text{ h.p.}}$$

Actual power used 200 h.p. For corrugated (or step) surfaces on the interior, additional 10% h.p. is required as for compartment (1).

1710. **Closed Circuit or Open Circuit Grinding.** BORNER, H. *Pit & Quarry*, Aug. 1954, **47**, 117–20, 123–5; (Translation from *Zement-Kalk-Gips.*, Aug. 1952, **5**, 242–52). The performances were judged from size and specific surface and from strength tests, and from the relations between these, and the work per hour to create a standard amount of new surface. Conclusions are: (1) the closed circuit grinds selectively, i.e. more finely. Open circuit overgrinds the easier grinding components; (2) closed circuit permits a simple control of strength producing surface by the adjustment of a constant circulating load; (3) output does not depend so closely on optimum load-filling in closed as in open-circuit grinding; (4) for same strengths of finished cement, the output in closed circuit is 30% higher than with open circuit, with high grindability slag, and 18–12% with low grindability slag; (5) the temperature (grinding) is 175°–195°F in closed circuit as against 250°–265°F for open circuit. Summary: The more different the grindability (the harder and the heavier being most valuable), the higher the economic value of closed circuit. Conversely, the superiority of the closed circuit is less, the more homogeneous the materials and the lower the grindability. The additional cost of equipment, under German conditions, is only justifiable for surface areas over 4000 (Blaine). Graphs. 17 refs., mostly on cement. Results with Blaine's apparatus are corrected according to Arnell and Swanson. [P]

1711. **Increasing the Efficiency of Cement Ball Mills.** CAPEK, Z. *Stavivo*, 1950, **28**, 286; 1951, **29**, 695. *See under* Ball Mills. [P]

1712. **Relationship of Mill Charge to Surface Area of Cement.** CHANDLER, W. R. *Rock Prod.*, 1935, **38** (9), 38–41. Method of determination of surface area by sedimentation, and the relation of the sizes found to the mill charge and strength of cement are given.

1713. **Researches into Wet-Grinding Hydraulic Binders.** CHASSEVENT, L. *Chim. et Industr.*, 1947, **57**, 327. Compared with dry-grinding, wet-grinding offers the advantages of simplicity and economy in the manufacture of blast-furnace slag cements. Special precautions are necessary, however, to ensure constant and suitable cement: water ratio in concrete so prepared. It is suggested that trials of this method should be restricted to central concrete establishments, where rigid control can be exercised. Wet-grinding is more difficult to effect satisfactorily with binders which react quickly in contact with water, as, for example, artificial cements, than with blast-furnace slag. Old slags can be reduced to a powder which reacts quickly in a basic medium by wet-grinding; these are difficult to grind dry.

1714. **Increase of Effective Diameter of Inter-compartment Partitions Area in Cement Grinding Mills.** DANUSHEVSKI, S. I. *Byull. vsesoyuz. nauch.-issled. Inst. Tsement.* (*Bull. All-Un. Cement Res. Inst., U.S.S.R.*), No. 23, 1938, 135. *See also under* Karyakin.

1715. **Tests on [Cement-clinker] Grinding Aids.** DAWLEY, E. R. *Cement & Lime Manuf.*, 1944, **17**, 1–4. The effect on the number of mill revolutions required to increase the sp. surface from 800 to 1800 sq. cm/g was studied for a 50-lb batch of a clinker containing 3·5% of gypsum. 0·07% of insol. rosin (I), cod oil (II), beef tallow, Nopco 1900 (III), Nopco Plastol No. 1 (IV), kojic acid (V), and Al stearate (VI); all reduced the revolutions required by 32·5–24%, in that order; powdered Al stearate and clinker without added gypsum required 6·5 and 11·6% more revolutions. (VI) increased the tensile strength, (II), (V) and (VI) the compressive strength, (I) the resistance to freezing and thawing, and (II), (III) and (IV) the resistance to the temp. cycle of the concrete made from the ground clinkers. *See also Pit & Quarry*, 1943, **36** (7), 57.

1716. **Can the Result of Grinding be Predetermined?** FRENAY, E. and COLLEE, R. *Rev. univ. Min.*, 1950, **6** (11), 370–9. An attempt is made to develop a graphical method of controlling, on the basis of the physical data of the equipment, the grinding operation to produce sizes between certain limits. Examples are given for normal equipment for grinding ores or clinkers. Abstract from *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1951, **15** (6), 584.

1717. **Law of Size Distribution.** FRITTS, S. S. *Rock Prod.*, 1941, **44**, 64, 90; *Ceramic Abstr.*, 1941, **20**, 268. The author discusses the theory of grinding as a phase of the problems dealing with surface-area measurement of cement and cement raw materials. Equations and means of obtaining the necessary data for them to determine the actual mean diameter of the 0–7·5-micron fraction are given; from these data the surface area may be determined.

1718. **Grinding Plant Research. Parts 1–9.** GILBERT, W. *Rock Prod.*, 1931, **34**; 1932, **35**. Several parts deal with clinker grinding. *See* No. 1092. [P]

1719. **Grinding or Crushing Cement.** GODDARD, J. F. *Brit. Pat.* 350538, 1930. In the dry grinding of cement clinker, gypsum, etc., a segregating agent such as resin or a resinous material is mixed with the material to be ground in order to impart a dispersive propensity to the pulverized particles. In the manufacture of cement, 1 part of resin to 5 parts of plaster of Paris or hydraulic cement may be used, and 1 part of this mixture is added in the mill to every 200 parts of cement.

1720. **Mechanics of Present Pulverizing Practice.** HAWKSLEY, P. G. W. Proceedings. Pulverized Fuel Conference, 1947, 656–87, Institute of Fuel. 2 gns. An interim report of investigations in progress. The information is collected from answers to questionnaires sent out to the electrical and cement industries, the greatest users of pulverized fuel, as to plant layout, operating conditions and abnormal occurrences. Performance data of mills in various districts are tabulated, and analysis is made of the power consumption as distributed between fan consumption, drying, grinding and feeding. The U.S. ball mill grindability index is discussed in relation to practice. 22 refs. An

approximate calculation of the drying capacity of pulverizers is given in a short appendix. [P]

1721. **Multi-Chamber Mills with Air Separation for Superfine Cement.** A. B. HELBIG. *Cement*, 1932 (5), 108–17. The grinding of cement is discussed in relation to the greatly increased demand for superfine cement, the strength of which far exceeds the specification requirements. Fine grinding in one operation is not good practice, and it is considered that the process will develop into a pre-grinding to a max. size of 0·5 mm, followed by a fine grinding with air separation, the latter grinding being best effected in multi-chamber mills.

1722. **Economical Crushing Practice (in the lime, cement and gypsum industries).** HODEL, J. *TonindustrZtg*, 1941, **65**, 17–8, 37–9. Factors determining the design of closed-circuit crushing plant are discussed.

1723. **Modern Portland Cement Production.** HULL, W. Q., HASS, P. and FRANKLIN, P. *Industr. Engng Chem.* (*Industr.*), 1954, **46** (5), 830–42. Pp. 835–6 describe the reduction of rock and clinker. Flow sheet.

1724. **The Simultaneous Grinding of Granulated Slag and Cement Clinker.** IVANOV, A. N. and PAMYAN, V. K. *Tsement*, 1939, 6–15. *Build. Sci. Abstr.*, 1941, **14**, 69.

1725. **New Trends in Grinding Cement in Foreign Plants.** KARYAKIN, S. F. *Byull. vsesoyuz. nauch.-issled Inst. Tsement.* (*Bull. All-Un. Cement Res. Inst., U.S.S.R.*), No. 23, 1938, 154. 17 pp., 7 figs. *See also under* Danushevski.

1726. **Grindability and Physical and Chemical Characters of Portland Cement Clinker.** KARYAKIN, S. F. *Byull. vsesoyuz. nauch.-issled Inst. Tsement* (*Bull. All-Un. Cement Res. Inst., U.S.S.R.*), No. 23, 1938, 81. 20 pp., 6 figs., 4 tables.

1727. **Bearings from Pressed Plastics for Use in Preparation Machines.** KISSLER, R. *TonindustrZtg*, 1941, **65**, 510. Data are tabulated on the use of pressed plastics in the bearings of cement mills, stone crushers, roller crushers concerned with mining, roller crushers 750 mm diameter × 500 mm, and centrifugal mills 1750 mm crate diameter. Precautions to be taken when using plastics for this purpose are enumerated; if these are observed the life of the bearings will attain to or even exceed, that of metal bearings.

1728. **Milling at the Permanente Cement Plant.** KIVARI, A. M. *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, 1942, **148**; *Tech. Publ. Amer. Inst. Min. Engrs*, 1359, 24 pp. The grinding schedule involves the closed-circuit grinding of the limestone and clay separately.

1729. **Efficiency of Raw Grinding Mill with Increased Inter Compartment Partitions Area of Cement Plant in Podgorenka.** KORSHUNEWA, A. I. *Byull. vsesoyuz. nauch.-issled Inst. Tsement* (*Bull. All-Un. Cement Res. Inst., U.S.S.R.*), No. 23, 1938, 146. 8 pp., 2 figs., 7 tables. [P]

1730. **The Operational Performance of Separators.** KRAUS, F. *Zement-Kalk-Gips.*, 1954, 273–81. The performance of various types of crushers is compared using cement clinker. Precrushers and finishing crushers were compared as well as air and centrifugal classifiers. The short ball mill and centrifugal separator in closed circuit were found to be far the best. Illustrations. [P]

1731. **Grinding Problems in the Cement Industry.** KUHL, H. *TonindustrZtg*, 1949, **73**, 29, 63. A detailed review is given of the existing methods of computing the specific surface of a finely-ground material. The calculation is explained for the cases where high accuracy does not matter; these calculations are based on the Rosin–Rammler–Sperling law of grain distribution, which is stated to be the most suitable for the majority of finely-ground materials, and especially for cements. It is concluded that there is a great discrepancy between the theory of grinding and the efficiency of the present grinding equipment. 5 figs.

1732. **Handbook for Cement Engineers.** LABAHN, O. Bauverlag, G.m.b.H., 1954, pp. 124, DM.8. A chapter on crushing and grinding and raw material mixing. 29 illustrations.

1733. **Why and How Wet Ground Cement was Used at the Port Barrage.** LANGAVANT, C. de. *Rev. Matér. Constr., C.*, 1952 (438), 81–5; (439), 105–8; (440), 123–8. (Summary in English.) The Bort dam is probably the first in Europe where a cement plant has been put up on the site. The cement was made by wet grinding of blast-furnace slag, produced 360 miles away. The ooze produced was mixed with Portland cement which acted as a catalyzer. The results were fully up to requirements.

1734. **The Specific Surface of Fine Powders.** LEA, F. M. and NURSE, R. W. *J. Soc. chem. Ind.*, 1939, **58**, 277–83. A study of Carman's permeability method (*Proc. Amer. Soc. Test. Mater.*, 1935, **35** (II), 457) has been made together with a comparison of the Wagner photo-electric sedimentation method and the Andreasen pipette method. Good agreement among the methods is obtained, but the permeability method is rapid and of good reproducibility, but other methods are necessary if size distribution curves are required. The use of liquids has been found to give high results when the specific surface exceeds about 1000 sq. cm/g, an air permeability method is found satisfactory for cements up to 4000 sq. cm/g, and should be applicable to other fine powders. 1 ref.

1735. **Relation of Ball Load to Clinker Charge in Grinding Mills.** LOVELAND, R. A. *Rock Prod.*, 1952, **55** (10), 96–8; *Zement-Kalk-Gips.*, May 1953, 184–6. Laboratory ball tube mill clinker grinding tests are described. With one exception the data indicate for batch mills and by inference for continuous mills, that the ratio of ball load to clinker charge should be approx. 15 for power economy, when grinding to type I cement fineness. In commercial mills the ratio is considered to be less than 15, and redesign is recommended. Ratios greater than 15 are indicated for type III fineness, and possible power savings appear to increase with higher fineness. Application of the findings to commercial closed circuit grinding and ball tube mill design are discussed.

1736. **Die Hartzerkleinerung (1867–1949).** (Crushing and Grinding.) MITTAG, C. 1953, Springer Verlag, Berlin, pp. 118–43. The tube mill in the cement industry is dealt with and tabulated performance data are presented. [P]

1737. **Expansion of Portland Cement Works, Alpena, Michigan.** NORDBERG, B. *Rock Prod.*, 1955, **58** (1), 102. Two new mills $9\frac{1}{2} \times 15$ ft, 19 rev/min, with 700-h.p. a.c. synchronous motors, by Allis Chalmers are installed. Ball loads are 107 000 lb of 1–3-in. forged steel balls. Closed circuit. Uses Hardinge's electrical ear. 45 tons per hour of kiln feed as product.

1738. **Closed Circuit Grinding.** PERRY, J. H. *Chemical Engineers' Handbook*, 1950, pp. 930–7. All aspects of closed-circuit ball-mill grinding are discussed, including wear and power consumption. A section deals with cement raw material grinding.

1739. **Proportioning Ball Loading in Tube Mills to Reduce Power Costs.** PRAILLE, E. *Rock Prod.*, 1950, **53** (10), 109, 136; *Ceramic Abstr.*, 1951, **34**, 89. In a mill for grinding cement clinker, the second and third compartments have five horizontal compartments. Grinding media for the two adjacent compartments have the same weight. The grinding surface, however, is more than doubled, resulting in a 20% power saving. [P]

1740. **An Analysis of the Results of Classification of Ground Cement Ingredients.** RAMMLER, E. and PROCKAT, F. *Zement*, 1934, **23**, 557–61. Full tabular comparisons are presented. [P]

1741. **Rational Cement Grinding.** RICHARZ, H. *Cement & Cem. Manuf.*, 1931, **4**, 1226–30. The degree of efficiency of the tube mill must be considered in relation to the hourly output, screen analysis, and power consumption. The weight and size of the ball charge in a three-compartment mill are discussed. The maintenance of a good current of air through the mill is an important factor.

1742. **Preliminary Crushing of Raw Materials for Cement.** Rock, E. *TonindustrZtg*, 1940, **64**, 269–70. Calculation of output is illustrated.

1743. **A Brief Résumé of Trends on Grinding in the Cement Industry.** Rockwood, N. C. *Rock Prod.*, 1938, **41** (1), 60–3. Flow sheets of various cement plants with particular emphasis on the plant of the Allentown Portland Cement Co.

1744. **Coal Pulverizers and Grinding.** Rosin, P. *Ber. Reichskohlenrates*, No. 25; *Zement*, 1931, **20**. Compares grinding practice in cement works and in large power stations. Deals with all kinds of mills. The development is traced of pulverizers, and particularly of large mills and pneumatic conveying and classifying techniques, air-swept mills, mill drying and unit-firing systems.

1745. **Improving Grinding.** Rugen, C. D., Kivert, J. A. and Boehler, R. E. *Rock Prod.*, 1940, **43** (3); 33–4. *Ceramic Abstr.*, 1940, **19**, 261. First of a series of three articles, covering an investigation of grinding installations. The present article deals with the grindability of raw materials and clinker. 50% more work is done in 1940 than 15 years ago, when only 1200 sq. cm/g was produced as compared with 1800 sq. cm at present. Curves are presented showing surface produced under different conditions.

1746. **Experiences in Grinding Raw Materials for Portland Cement.** Rugen, C. D. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 185–96; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1893, 12 pp. The raw material for cement kilns should all be between 15 and 16 μ in size, with clay shale and slag (argillaceous material) in the finer size ranges. The characteristics of the various components should be studied to bring about this size distribution; a recommended system is one in which primary and secondary ball mills are used, each grinding in closed circuit with a classifier. The mills work best with a 43 volume-percentage ball load, and other working improvements are suggested. Figures for a dry-grinding ring-roll mill are given; these show that power requirements are greater than in the ball mill wet-grinding process.

1747. **The Dependence of Grindability of Cement Clinker and Limestone on the Properties of these Materials.** Schmid, A. *Schriftenreihe der Zement Industrie*, 1953, **14**, 7–29. (Verein deutscher Zement Industrie.) *See under* Grindability.

1748. **Analysis of the Efficiency of Cement Grinding Machinery in 1936 and First Half of 1937.** Shabadin, P. F. *Byull. vsesoyuz. nauch.-issled. Inst. Tsement.* (*Bull. All. Un. Cement Res. Inst., U.S.S.R.*), No. 23, 1938, 7. [P]

1749. **Particle Size Distribution, Hygroscopicities, Surface Factors, Colloid Contents and Total Surface Areas of Ceramic Raw Materials, and the Relations between them.** Shiraki, Y. *J. Jap. ceram. Ass.*, 1956, **64** (7), (726), 151–61. Particle size distribution, hygroscopicity, colloid content, etc., were measured directly; surface factors and total surface area were calculated from the data, and the relations between them are discussed. The data for about 100 varieties of 9 ceramic materials are fully tabulated and size distributions are also presented in graphs. The relations between four of the fundamental properties are also set out in graphs. The headings and other details of the tables and graphs are in English. The text is in Japanese. 51 refs.

1750. **Belgian Experiments in Clinker Grinding.** Slegten, J. A. *Rock. Prod.*, 1946, **49** (9), 60; *Build. Sci. Abstr.*, **19**, 325. *See* No. 1166.

1751. **Colloidal Carbon as Grinding Aid in Cement.** Sweitzer, C. W. and Craig, H. E. *Industr. Engng Chem.* (*Industr.*), 1940, **32** (6), 751–6. A dosage as low as 0·32% on the clinker will increase fineness by 30%, or decrease time of grinding by 28%. Increased dosage makes for still greater increases in output. Data are tabulated for effects on fineness and also on strength properties of the cement. 2 refs. (1) A.S.T.M. on Cement, 1928; (2) Columbian Carbon Co., 'Columbian Colloidal Carbon' pp. 141–5, 1938. [P]

1752. **Cement.** Taggart, A. F. *Handbook of Mineral Dressing*. 1950, Wiley & Sons,

New York; Chapman & Hall, London. Raw materials Crushing and Grinding, Chap. 3A, pp. 07, 29, Chap. 6, pp. 01, 10, 29, 46. Clinker Crushing and Grinding, Chap. 3A, pp. 25–6, 29; Chap. 6, pp. 09–49. In Chap. 3A, costs of grinding are tabulated. In Chap. 6, dry grinding of various materials and with various machines is described and performance figures are tabulated including some for cement. [P]

1753. **A Study of the Particle Size Distribution in a Concentra type Mill.** TANAKA, T. and SAITO, N. *J. Jap. ceram. Ass.*, 1952, **60**, 99. The fineness of cement clinker was determined after it had been ground in a concentra mill, divided into 5 segmental chambers. Plots of the 0·088-mm oversize against the distance from the mill entrance showed that the rate of progress of a particle through the mill is not uniform. Rittinger's law was shown to be approximately valid if the rate of movement of the powder was assumed to be constant. The exponential law for particle size distribution was also valid. The grinding rate equation was derived from partial differentiation of the empirical exponential equation, and the most effective conditions of operation were deduced. 5 figs., 1 table. *See also ibid.*, 1952, **60** (672), 228–30; Ball Mill Grinding Studies of Several Ceramic Materials. Specific surface areas by Blaine's method are compared with the residues on a 0·088-mm sieve (150 mesh).

1754. **Notes on the Determination of Flour in Cement.** TAYLOR, EDUARDO. *Rock Prod.*, 1932, **35**, 46. Sedimentation apparatus is described and its method of operation.

1755. **A Rapid Method for the Determination of the Specific Surface of Portland Cement.** WAGNER, L. A. *Proc. Amer. Soc. Test. Mater.*, 1933, **33** (2), 553.

1756. **Grinding Techniques.** WALTER, J. *Rev. Matér. Constr., C.*, June/July 1952 (441), 163–9; (442), 193–6. 2% of the French electrical energy production is employed by processes in the cement industry. 70% of the total energy employed in the cement industry goes into the grinding processes. Thus there is ample room for improvement. The author presents a general account of the processes used, accompanied by illustrations (for the most part of ball mill operations).

1757. **Pulverizing Cement Raw Materials.** WATANABE, K. *J. Jap. Ceram. Soc.*, 1942, **50**, 162; *Ceramic Abstr.*, 1949, **32**, 223.

1758. **Cement Manufacture: Grinding of Clinker.** WILSNACK, G. C. (Edison Cement Corpn.). *U.S. Pat.* 2186792, 1940. 0·08–0·33% of carbon black of colloidal fineness is added to the clinker prior to grinding. Time and power for grinding are reduced, as is also the proportion of H_2O necessary to form a plastic mortar or concrete.

1759. **Method for Estimating the Efficiency of Pulverizers.** WILSON, R. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 810, 1937. Applications to cement clinker, 15 pp., *see* No. 156.

1760. **Grinding of Material (Portland Cement).** WITTE, G. A. (International Precipitation Co.). *U.S. Pat.* 1803821, 1931. By grinding Portland cement in air of lower r.h. than that of the atmosphere conveniently attained merely by heating the air and/or the cement, the grinding time for a certain fineness is much reduced and the setting times are maintained.

1761. **What is in the Future for Grinding?** WOLFE, J. M. *Rock Prod.*, 1947, **50**, 119. Grinding practices and cement plants used in America during the past fifty years are reviewed, and the progressive stages are traced through which two-stage, closed-circuit wet raw grinding has been evolved since the American Portland cement industry was firmly established. In recent years the raw grinding department has undergone the most radical alterations of any plant section, beginning with conversion to the wet process, which involved the introduction of hydrometallurgical equipment which was not previously applied in the cement industry. In the future grinding systems must be readily adaptable to meet commercial situations as created by the market demand for cements. 15 figs.

1762. **Short Ball Mills for Dry-raw and Clinker Grinding.** WOLFE, J. M. *Pit & Quarry*, 1953, **46**, 99–102.

1763. **Relation between Weight per Litre and Ease of Grinding of Cement Clinker.** ZLATANOS, B. *Rev. Matér. Constr., C.*, 1954 (461), 47–50. Cement strength is not related to the weight/volume ratio of the clinker, but to the fineness of grinding. A dense clinker (1200–1400 g/l.) is less easily ground than a lighter one. The fuel saving when the clinker is fired to give 1200 g/l. instead of 1300 g/l. is about 6½%. The heat required to obtain clinkers of 1200, 1300 and 1400 g/l. is calculated, tentatively, as about 1060, 1125, 1170 kg cal per kg of clinker, respectively.

CERAMICS: CLAY

1764. **The Hammer Mill for Clay Grinding.** ANON. *Brick Clay Rec.*, 1940, **97** (5), 29; *Build. Sci. Abstr.*, 1941, **14**, 50. A brief review is given of a few installations using hammer mills in the preparation of clays. A typical hammer mill, whereby material is broken up by impact rather than by rolling or crushing, is described. Such mills are suitable for crushing run-of-pit shale or clay to as fine a mesh as desirable, many types being equipped so as to eliminate clogging. It is stated that the use of hammer mills results in improvements in particle sizing for some clays, as well as increased output and efficiency of pans.

1765. **Hammer-Mill Grinding of Dry Pan Tailings Reduces Pyrite Specking in Sewer Pipe.** ANON. *Brick Clay Rec.*, 1943, **102** (1), 33.

1766. **Crushers and Crushing.** ANON. *Brick Clay Rec.*, 1952, **121** (5), 54–6. A discussion of crushers, crushing methods and the materials to which each are best suited, with particular attention to clays. Illustrations.

1767. **Crushing Rolls.** ANON. *Brick Pott. Tr. J.*, 1914, **22** (1), 19–20. Description of toothed rolls to give a preliminary crushing, after which the product will be gripped by plain rolls placed beneath. Other features of clay reduction are discussed and suggestions made.

1768. **Grinding Broken Saggars.** ANON. *Brick Pott. Tr. J.*, 1922, **30**, 208. The suitability of the various types of grinding machines is discussed.

1769. **Research and Ceramics, 1951.** *Res. Pap. Brit. Ceramic Res. Ass.*, No. 175, Sept. 1952. Pp. 38–40 give a review of recent literature on crushing and grinding, screening, separating and filtering, with bibliography, accompanied by 35 refs.

1770. **Watt cuts Clay Preparation Costs.** ANON. *Ceramic Ind.*, 1951, **56** (6), 90; 1952, **57** (3), 33. At the Watt Pottery Co., U.S.A., a pulverizer is in use which dries and pulverizes the clay, and gives a product of uniform size and moisture content. 8 figs. (*See under* Mahler, Drying and Grinding.)

1771. **Cylinder Grinding.** ANON. *Ceramics*, 1950, **1** (11), 576–81. Although grinding pans are still extensively used, increased interest is now being shown in cylinder grinding. The Hardinge (conical) ball mill is illustrated and described. Factors affecting the operation are examined individually. Ancillary equipment is also illustrated. 3 figs.

1772. **Bone. Its Preparation and Use in the Bone China Body.** ANON. *Ceramics*, Aug. 1952, **4** (42), 56–62. Pan grinding is still the usual method of grinding charred bone for the manufacture of bone china clay bodies. The material is relatively soft and the pan lining lasts for ten years. Time required is 8–24 hours for each batch. Cylinder grinding is sometimes used for this purpose.

1773. **Continuous Grinding in the Ceramic Industry.** ANON. *Chem. metall. Engng*, 1924, **30**, 783–4. A description of the new plant of the Amer. Grinding Co. Felspar, silica and clay are ground by a continuous process to −200 mesh. The raw material is ground wet in a Hardinge mill, passes through two Dorr classifiers and a Dorr thickener, is dewatered on a vacuum filter and delivered to a tunnel drier.

1774. **Potter's Mills.** ANON. *Elect. Rev., Lond.*, 1946, **139** (3594), 559-63; *Pott. & Glass, Lond.*, 1947, **25** (2), 38–41. The application of electricity to the milling of flint and stone for the production of pottery is described in detail. Pan, cylinder and continuous grinding are touched upon, and specific mention is made of the substitution of electric power for steam in certain British mills, giving motor horsepower, etc. 1 diagram, 8 photographs.

1775. **Progress in the Design of Machinery for the Ceramic Industry.** *Progressus*, 1953, **5** E.2, 45–8. Most ceramic specialists find that water has to be used to attain the required fineness of ingredients and wet grinding is therefore called for. Some types of wet grinding mills are illustrated.

1776. **Experiences in the Application of Impact Mills in the Brick Industry.** ANON. *Ziegelindustrie*, 1953, **6**, 305–6. It is regarded as superior to other mills for crushing clay for the brick and tile industry. The advantages are described individually.

1777. **Dry Grinding Clay to Eighty-Mesh.** ALBERY, D. F. *J. Amer. ceram. Soc.*, 1927, **10**, 804. A description of two installations for grinding a terra cotta clay to 80 mesh is given. The necessity for fine grinding is explained and the difficulties encountered in development of process are enumerated. Advantages of finely-ground clay and the use of air separation are described. The Marcy rod mill and the Hardinge mill are described.

1778. **The Preparation of Ceramic Raw Materials. I and II.** AVENHAUS, W. *Ziegelindustrie*, 1949, **2**, 253, 276; 1951, **4**, 422. A general account of preparing any kind of raw material by segregation, crushing and mixing is given. Reduction to small pieces can be done by a crusher, roller, edge-mill or ordinary mill. The use of pairs of rolls running at different velocities does not prevent the agglomeration of lime impurities at certain points, and, after milling, a separate mixer is necessary as with ordinary rolls. The high rate of wear and high power consumption of differential rolls makes them uneconomical. The edge-mill and other types of mill combine grinding and mixing. The grinding work done by these machines can be determined by well-known methods. Useful numerical dimensions and relative values are still wanting for the determination of the work performed in mixing. In the planning of crushing plants the hardness, the largest diameter of the material to be crushed, and the diameter aimed at, have to be considered. Mixing and separating in general, screening, elutriation, and air separation are discussed. Stone separators are generally unsatisfactory. The manner in which clay particles become plastic is treated. The highest degree of plasticity is reached at a certain optimum water content characterized by Pfefferkorn's plasticity number. Kneading, treading, and the various ways of ageing are listed. Every ceramic raw material can be refined by preparation. Suitable preparation of the raw material is recommended especially for the heavy clay industry, where at present it is being considered far too little.

1779. **Experience with the Combined Grinding and Drying of Clay.** BALKEVICH, V. L., DOBROVOLSKY, I. S. and ZAYOUTS, R. M. *Glass & Ceramics, Moscow (Steklo i Keramika)*, 1951, **8** (2), 12; *Trans. Brit. Ceram. Soc.*, 1951, **50** (9), 377A. A Russian Institute has built and tried out an installation for the simultaneous grinding and drying of clay. This is described.

1780. **Further Ball Milling Studies on Pure Oxides.** BENNETT, D. G. and MCCREIGHT, L. R. Dept. of Ceramic Engineering, Illinois University, Oct. 1949. Copies available from: Lending Library Unit, D.S.I.R. Ref. 0714/43. The effects of milling time, type of mill and lubricant used on the compressive strengths of pure oxides and magnesia bodies are described. Experimental results indicate that the strength value of formed pure oxide bodies was increased by milling the fused raw material in a non-aqueous medium such as alcohol. [P]

1781. **The Wet-Grinding of Ceramic Raw Materials and of all Hard Materials.** BLOTTEFIERE, R. de. *Rev. Matér. Constr.*, 1935 (314), 161B.

1782. **Grinding Clays.** BROWN, D. *Brick Clay Rec.*, 1924, **64**, 734. No radical change in methods for grinding clays for brick making has taken place within the last 30 years, though machines have been improved in constructional detail. Lumpy clays should first be passed through a granulator before grinding. For clays containing many stones, a conical or beaded roll crusher should be used. For best results, the material should be fed continuously at an even rate by means of a feeder or granulator. Dry pans are employed for clays having less than about 10% moisture. From 60 to 75% of the power required to drive a dry pan is used up between the screen plates and the scraper, and not in the actual grinding. Other less common types of mills are briefly discussed.

1783. **Dispersing Clays in a Colloid Mill.** BURDICK, R. *Bull. Amer. ceram. Soc.*, 1945, **24**, 160. *See under* Colloid Mills.

1784. **Simultaneous Grinding and Drying Clays for Dry Press Brick Making.** BUTKEVICH, V. M. *Glass & Ceramics, Moscow (Steklo i Keramika)*, 1952, **9** (10), 14–7; Translation by Cass in *Brit. Clayw.*, Aug. 1953, **62** (736), 154. An air-swept hammer mill was used. Results were quite satisfactory. There was no clogging. Performance and results from several tests on two mills are tabulated.

1785. **Machine for Pulverizing Clay.** CAMMIS, E. *Pott. Gaz.*, 1915, **40**, 95. Sketch is given of a self-cleaning pulverizer, in which use is made of a rotary brush to spread the material over the perforated grids.

1786. **The Griffin Mill for Pottery Grinding.** CARR-HILL, W. F. *Trans. ceram. Soc.*, 1916, **15**, 60.

1787. **Scientific, Technical, and Practical Study of Grinding and of the Preparation of Stoneware Bodies.** CHALMEL, F. *Céram. Mat. Constr.*, 1933, **36**, 235. The investigation was carried out to study the effect of the different methods of grinding and of preparing the body on eight different mixtures. The results point to the following practical conclusions: felspathic rocks should be dry-ground to leave not more than 2% on a 200-mesh sieve and clays dry-ground to pass a 20-mesh if they do not contain much impurity, otherwise they must be ground to fine powder. Fine grinding of a mixture favours homogeneity, plasticity, cohesion and reduces deformability in the kiln. Sharp-cornered grains favour cohesion and increase the resistance to compression, flexion, and wear and tear. Body compositions should have a vitrifiable clay base with moderate additions of a less fusible felspathic rock, and if necessary with a small addition of a fusible felspar. [P]

1788. **Improvements in and Relating to a Method and Apparatus for Pulverizing Clay.** COMBUSTION ENGINEERING SUPERHEATER INC. *Brit. Pat.* 652035, 1951. Clay is ground by a number of rollers in the lower part of the grinding unit, an air stream takes the product out of the mill.

1789. **Manufacture of Heavy Clay Products.** COULHON, A. *Rev. Matér. Constr., L'Industr. Céram.*, 1948 (386), 104. In the preparation of the fines for use in the batch of any ceramic product, the raw material must be passed through a series of grinding machines. The material itself should be dry (less than 2% moisture). The shape of the resulting particles is important, and is governed not only by the nature of the material and the method of grinding, but also by the design of the screens. Cylinder grinding is stated to give a lamellar product, whereas edge-runners give a more spherical material. Horizontal screens with round apertures also favour the passage of spherical particles, whereas the same type of screen inclined will pass more ellipsoidal grains. Primary crushers are divided into those of the hammer and those of the jaw type. Typical examples of these and of the edge-runner type of mill are described. 4 figs.

1790. **The Ratio of Water to Solids in Cylinder Grinding.** CREYKE, W. E. C. and WEBB, H. W. *Trans. Brit. Ceram. Soc.*, 1941, **40**, 55–72, Discussion 73–5. The important

feature is the viscosity of the charge, not the exact ratio, water to solids on grinding efficiency. Tables, graphs, 35 refs. *See* Nos. 630 and 1066.

1791. **Wearing Properties of Some Metals in Clay Plant Operation, Part I—Pug Mill Knives, Muller Tires, Runner Plates, Screen Plates.** DIERKER, A. H. and EVERHART, J. O. *Bull. Ohio Engng Exp. Sta.*, No. 97, 1937.

1792. **The Simultaneous Grinding and Drying of Clay.** ESSERE, G. *Rev. Matér. Constr., L'Industr. Céram.*, 1952 (433), 257. Soc. Stein and Roubaix, Paris, have now perfected a process for grinding and drying clay, thereby reducing to 1% or 2% the moisture which might amount to 20% in wet weather. Equipment is described, and the possibilities are considered good. A Raymond hammer mill is used together with air draught, separator, cyclone, deduster and ventilator.

1793. **Crushing and Storage: How they should be worked in a firebrick plant.** EVERHART, J. O. *Brick, Clay Rec.*, 1948, **112** (2), 66. Since the advent of grain-sizing, grinding has become an important part of the forming process. There is so much difference between clays that no set rules can be given for grinding. Screening is important for improving quality and reducing grinding costs. The screens must be kept clean and should never be pounded with a club or board. Vibration and slope of the screen need careful adjustment. Baffle boards should be used to distribute the clay evenly over the surface of the screen. When several separations are to be made, the screens should not be arranged parallel, one on top of another, but should be placed in a zig-zag pattern. 3 figs., 1 table.

1794. **Grinding and Pneumatic Grading.** GILSON, P. *Rev. Matér. Constr.* (Sect. B), 1947 (381), 325–6; *Brit. Ceramic Abstr.*, 1948 (3), 108A. A brief account of a ball mill suitable for grinding ceramic ingredients with air classification and oversize return.

1795. *Crushed Stone Production.* GOLDBECK, A. T. *Proc. Amer. Concr. Inst.*, 1954, **50**, 761–72. The processes from prospecting to the production of stone sand are described briefly. A list of 71 references is given.

1796. **Some Factors Affecting Mixing Processes in the Ceramic Industry.** GOODSON, F. J. and DODD, A. E. *Trans. Instn. Chem. Engrs, Lond.*, 1951, **29** (3), 332–41. A description of the processing of clays, etc., and of the factors affecting the properties of the slip and the extruded body. From the survey it will be appreciated that in general, grinding and mixing are inseparable in the ceramic industries. Any theories must include both operations, but up to the present, insufficient work has been done upon which a full theory can be developed. Greater control is required on all stages from winning the clay to the actual forming operation, and this symposium has focused attention on the need for a scientific investigation into the mixing and kneading problems of the ceramic industry.

1797. **Effect of Grinding on Kaolinite.** GREGG, S. J., PARKER, T. W. and STEPHENS, M. J. *Clay. Min. Bull.*, 1953 (2), (9), 34–44. The disintegration of china clay on grinding, then the agregation of the fine particles (readily separated again by an air stream), and some chemical decomposition into free alumina and silica are described.

1798. **A Study of the Effect of Grinding on Kaolinite by Thermo-gravimetric Analysis.** GREGG, S. J. *Trans. Brit. Ceram. Soc.*, 1955, **54** (5), 257–61; *J. appl. Chem.*, 1954 (4), 631–2, 666–74. The method gives information as to the strength of binding of structural water, and as to the structure of kaolinite. Readings were taken of the loss in weight against time under constant rate temperature rise. With unground kaolinite the curve dw/dT against T shows a peak at about 500°C due to loss of structural water. On grinding for periods up to 1000 hours, the peak is progressively broadened and shifted to lower temperatures but the total loss is unchanged, signifying that the lattice is distorted but not destroyed by grinding (ball milling). The conclusion is supported by X-ray analysis and by data for solution in hydrochloric acid. The specific surface (by nitrogen adsorption) increases and density falls. The mechanism probably entails the two

opposing processes of disintegration by shear and fracture of platelets and reaggregation by adhesion. Graphs. 3 refs.

1799. **The Preparation and Plasticity of Porcelain Mixes.** GREINER, E. *Ber. dtsch. keram. Ges.*, 1950, **27**, 99; 1951, **28**, 421. Discussing the influence of the method of grinding on plasticity it is suggested that, during grinding, crystals should be moved parallel to their plate structure, not destroyed by impact as they are in cylinder grinding. The superiority of bodies made in the old days with chaser mills is attributed mainly to a more careful grinding which preserved the platy structure.

1800. **Use of the High Speed Stone Attrition Mill for Glaze and Body Preparation.** HANSARD, W. C. *Bull. Amer. ceram. Soc.*, 1955, **34** (4), 115–6. The mill homogenizes and disperses, and consists of a vertically-driven shaft, with horizontal milling elements of vitrified aluminium oxide. The premix to be milled is first introduced into the cone-shaped feeding vortex between rotor and stator, and is forced between the faces of the milling elements to the discharge spout. A size distribution of electrical porcelain glaze shows the product as 100% finer than 33 microns down to 20% finer than 1 micron. Fineness and output quantity are controlled by coarseness of the grinding elements and distance apart.

1801. **The Continuous System of Grinding Ceramic Materials.** HARDINGE, H. *J. Amer. Ceram. Soc.*, 1923, **6**, 548. The paper includes considerable data on the ball mill grinding of ceramic raw materials. [P]

1802. **Magnetic Separators in the Clay Industry.** HAWKER, T. G. *Brit. Clayw.*, 1952, **61** (728), 277–8. Magnetic equipment for avoiding damage to clay crushers and ensuring the quality of slip, etc. Seven types of separator are briefly described.

1803. **Some Clay and Shale Grinding Problems.** HENDERSON, L. A. *J. Canad. ceram. Soc.*, 1945, **14**, 13. Methods of grinding clay in order to overcome the difficulties of moisture content and stones, especially lime pebbles, are outlined.

1804. **Control and Segregation in Dry Grinding.** HENDRYX, D. B. *Brick. Clay Rec.*, Jan. 1954, 46. Includes a discussion on pan mills v. hammer mills. The dry pan is used more than any other in heavy clay industry because it is reasonably adapted to dry or wet, hard or soft, coarse or fine grinding and can be fed with small or large lumps. With a vibrating screen, and with small or large screen plates in the pan, it can control size distribution. Combines crushing with attrition; but with hard products, a ball mill should follow for brick materials. Capacity can be increased by speeding up the pan. The hammer mill has been regarded as having too expensive maintenance for refractory grinding. But if used without grates, up to 75% decrease in wear can be achieved. Wear occurs in the drag of the hammers over the slots. Hard welding rod increases life. The impact mill does more work on coarse material. The hammer mill should really do the coarse grinding and the pan mill should grind the tailings. Hammer mill uses less power per ton than the pan mill, first cost is much less, but is not always suitable for wet material. Plenty of fines can be produced on suitable materials.

1805. **Grinding in the Ceramic Industry.** JUNCK, G. *J. Soc. chem. Ind., Vict.*, 1940, **40**, 292–96. Brief description of dry pan and ball mill grinding.

1806. **Symons Crusher in the Ceramic Industry and the Universal Grinding Plant.** KIRCHHOFF. *Ber. dtsch. keram. Ges.*, 1941, **22**, 135; *Ceramic Abstr.*, 1941, **20**, 222. The objection to the ball mill and the edge mill, generally used for grinding, is that the product consists of rounded particles which are undesirable in ceramics.

1807. **Influence of Particle Size Distribution on the Properties of Nepheline Syenite.** KOENIG, C. J. *J. Amer. ceram. Soc.*, 1955, **38** (7), 231–41. Samples of nepheline syenite prepared by conventional and fluid energy (continuous loop) reduction methods were studied for (1) their fundamental properties, and (2) the characteristics they impart to vitreous bodies. Fluid energy grinding methods make it possible to obtain a powder

passing 325 mesh and yet not to contain excessive amounts of extreme fines. The absence of large flux particles is conducive to a uniform distribution of the resultant glassy phase which permits a closer approach to equilibrium conditions and improves the physical properties of whiteware bodies. 14 refs.

1808. **The Determination of Grain Size.** LEECH, L. G., RATCLIFFE, S. W. and GERMAN, W. L. *Trans. Brit. Ceram. Soc.*, 1953, **52** (3), 145–52. A note of the use of the Spekker Photometer and Rigdens' Apparatus. *See also under* Particle Size Determination.

1809. **Grinding of Clays.** LOMAS, J. *Mine & Quarry Engng*, 1953, **19**, 51–2. Clays for common grade products require little preparation before grinding, apart from removal of stones. Kaolin and industrial clays require purification, such as washing in presence of deflocculants. Grinding equipment is discussed, including the rotary crusher, double cage disintegrator and beater, flour, pebble hammer and roller mills.

1810. **A New Design of Clay Shredder.** MALCHENKO, V. I. *Fireproof Mat., Moscow (Ogneupory)*, 1949 (4), 414–5. 15–20 tons per hour are obtained with 30-h.p. motor. Drawing.

1811. **The Employment of Hammer Mills in the Ceramic Industry.** MASSIEYE, J. *Rev. Matér. Constr.* (Sect. B), 1953 (444), 155–8. *See under* Hammer Mills.

1812. **Preliminary Crushing of Fireclays.** MILLER, R. H., MUNRO, A. H. and CLINGAN, J. R. T. *Brick Clay Rec.*, 1945, **107** (1), 57. The authors give their individual opinions on the best methods of preliminary crushing: the type and location of the crusher, the effect on it of the hardness of the clay, weathering, and method of mining. The importance of the size of the material before and after crushing is also discussed.

1813. **On the Grinding Behaviour of Ceramic Bodies in Wet Cylinder Grinding.** MULLER, R. *Sprechsaal*, 1935, **68**, 613, 627. Experiments were carried out with raw kaolin in a wet cylinder mill, which in size, construction and operation corresponded with mills used in ceramic practice. The progress of the grinding process was controlled by fractional sieving of ground samples. The results of the experiments were studied both by the hyperbola method suggested by Mittag and by the exponential method, and the advantages of the latter are demonstrated. The grinding of the coarser ingredients of material is effected by the crushing action of the falling flints, while the grinding of the finer portions is due to the grinding action of the revolving flints in the bottom of the cylinder. A delay in the grinding process sets in with the fine grinding of the higher fractions, while the rise in viscosity as the grinding proceeds renders more difficult the grinding of the finer grains. Increasing the weight of flints reduced the number of revolutions necessary for fine grinding, but the grinding efficiency is lowered. Increasing the speed of the mill reduced the grinding time, but increased the number of revolutions. Increasing the weight of the individual flints while maintaining the same total weight considerably reduced grinding efficiency; the number of flints is the important factor. Increased speed with larger flints reduced the efficiency in proportion to the increase in speed. Reducing the water-content lowered the grinding efficiency, which could not be compensated for by increasing the weight of the flints. [P]

1814. **The Controlled Milling of Ceramic Materials.** PODMORE, H. L. *Ceramics*, 1952, **3**, 621; *Pott. Gaz.*, 1952, **77**, 1740. Compares the grinding resistance of two samples of felspar by grinding each with limestone and determining the specific surface of each after each experiment, both before and after dissolving out the limestone, then comparing each with the limestone surface.

1815. **Ball-Mills.** REINHOLD, K. *TonindustrZtg*, 1916, **40**, 102. Surprise is expressed that the advantages of the cylinder mill are so little known to brick and tile makers. The vertical runner mill, it is often said—and rightly so—grinds well moist and even wet material, although there are cylinders which are quite as good for wet grinding. With the ball mill for dry grinding power is economized and output increased. The material to be ground should always be kept at the same level in the cylinder, and

pebbles or balls be examined from time to time, so that their original weight and size may be kept up.

1816. **Dry Pan Investigations Using a Small Sample Technique.** RICHARDS, R. *Trans. Brit. Ceram. Soc.*, 1955, **54** (6), 367–87. A method for investigating the operation of a dry pan is described involving measurements on small samples of the outputs and presenting the results in the form of statistical control charts. From the charts reliable estimates of the inherent variability of the grinding pans are made and used to determine the precision of the averages finally quoted. A typical investigation described was designed to determine the effect on the output and fineness of the acceptable material produced, of using different settings of the idling position clearance between the rollers and the deadplate. It was found that at one works there was a marked increase in output and fineness when the clearance was changed from 2 in. to 1 in., although at two other works using nominally the same geological deposit no such effect was observed. It was concluded that reliable estimates of inherent variability can be made even to half-hour periods. The effects of modifications of the dry pan on output, etc., can be made. In the discussion a number of variables which might affect the experimental results was pointed out. [P]

1817. **The Milling of Pottery Materials and its Control.** RILEY, A. H. *Trans. Brit. Ceram. Soc.*, 1939, **38**, 561. Pan grinding of flint is discussed.

1818. **Milling and Materials.** RILEY, A. H. *Ceramics*, 1952, 4 (44), 120–8. The grinding of materials for pottery ware is discussed. Flints need calcining under controlled conditions before grinding. China stone is crushed in its natural state. The three methods of fine grinding are compared, with regard to costs: i.e. pan grinding, cylinder grinding and the Hardinge mill. Pan grinding is the most expensive method. Pulp characteristics, and the necessary mill conditions are discussed, together with effects of soda, calcium chloride and other governing factors.

1819. **Grinding in Stages.** SALGANIK, L. D. *Fireproof Mat., Moscow* (*Ogneupory*), 1948, **13**, 344. Flow-sheets are given for the crushing and grinding of various refractory raw materials. For quartzites a cone crusher effects a preliminary reduction to 50–60 mm; the material then passes to primary and secondary rolls which respectively reduce the size to 12–15 mm and 3–5 mm. After screening, the tailings are returned to the secondary rolls, the remainder, except for a fraction which is ground still finer in a tube mill, is passed to the storage bunker. An alternative procedure involves a preliminary screening into two fractions after the primary rolls; the finer fraction (5–10 mm) passes to the secondary rolls and the coarser fraction (10–15 mm) to the tertiary rolls. In this way three grain sizes are obtained: 1–5 mm, 5 mm and 5–8 mm. Silica flour is again produced in a tube mill. At one Russian silica brickworks using this scheme of crushing, the output was 15–20 tons per hour. Replacement of the cone crusher by a jaw crusher, and of the crushing rolls by edge-runner mills, led to a marked increase in output; the tube mill was omitted from the grinding circuit in this new scheme. A more accurately controlled grading can be attained by screening out the 5–12-mm fraction after the dry edge-runner grinding and passing the oversize to a second dry edge-runner, which yields a 5–8 mm-fraction. Finally, flow-sheets are given for a system of grinding having general application. After being crushed and passed through a preliminary grinding unit, the material is screened into two fractions; these are separately ground in further grinding units. 7 figs.

1820. **Developments in Fine Ceramic Machinery.** SCHLEGEL, W. *Ber. dtsch. keram. Ges.*, 1939, **20**, 18; *Ceramic Abstr.*, 1941, **20**, 122. In the installation of a conical tube mill, the feldspar or quartz is first broken by rollers, and the dried material is brought by a conveyor to a silo, from which it is conveyed uniformly to the tube mill. The ground material is taken by a bucket conveyor to an air separator and the material of the desired fineness is then automatically bagged. This installation produces about 1200 kg quartz ground to pass a 240-mesh sieve.

1821. **Microscope Examination of Ceramic Preparations.** SCHOBLIK, A. *Sprechsaal*, Sept.–Nov. 1953, **86** (17), (18), (19), (20), (21). A series of articles accompanied by photographs.

1822. **Ball Milling of Pure Ceramic Bodies.** SCHOFIELD, H. Z. *Bull. Amer. Ceram. Soc.*, Feb. 1953, **32**, 49–50. Experience in the laboratory is reviewed on ball milling pure ceramic bodies to fine grain sizes (order of 8 microns) without contamination. Mills lined with beryllium, carbon or rubber and employing balls of beryllium, zirconium, zirconia, magnesia and carbon have been employed successfully in various combinations to mill beryllia, magnesia, zirconium carbide and graphite. (Author's summary.)

1823. **Crushing Boulder Clays.** SEARLE, A. B. *Crush. & Grind.*, 1934, **2**, 155. The various types of mills in use, safety devices, separators and washing plants are discussed.

1824. **Crushing and Grinding Plastic Clays.** SEARLE, A. B. *Crush. & Grind.*, 1934, **2**, 209. For the purpose of a description of the methods of treatment, clays are divided into four groups: naturally plastic clays of different consistencies in various localities; clays in the form of rocks which can be crushed to powder; clays containing varying amounts of pebbles, etc., which can be crushed and remain in the mixture (brick and tile clays); and clays containing limestone, etc., which has to be removed.

1825. **Effect of Fine Grinding on Some Characteristics of Fine Earthenware.** SHIRAKI, Y. and MATSUMOTO, M. *J. Jap. Ceram. Soc.*, 1951, **59**, 443. Effects on such properties as thermal expansion and moisture absorption were studied.

1826. **Studies in Wet Grinding of Pottery Stone.** SHIRAKI, Y. and KAWANAMI, S. *J. Jap. Ceram. Soc.*, 1952, **60**, 412–6. 4 figs., 4 tables.

1827. **Clay Milling.** SHIRAKI, Y. and KAWANAMI, S. *J. Jap. Ceram. Soc.*, 1953, **61**, 4. The ball milling of Japanese china clays is studied. The relations between grinding time, fineness and viscosity of the mill charge are measured and the effect of the size of balls upon grinding efficiency is considered.

1828. **Studies in Clay Water Systems.** SHIRAKI, Y. *J. Jap. Ceram. Soc.*, June 1955, **63** (709), 233–43. Plasticity of clay. Torsional experiments on the plasticity of various clays are described. Plasticity of clay is very complex, and exact relations between plasticity and particle shape, size distribution, amounts of coarse grain in clay, protective colloid, exchangeable bases, time of ageing, etc., are not found. The Macey's 'bucklash' phenomenon is detected in many clays; it has no direct relation to the amount of colloid particle in clays or exchangeable bases, but it has a relation to their water contents. 26 refs.

1829. **Clay Preparation and Disintegration.** SPINGLER, K. *Ziegelwelt*, 1936, **70**, 149. The development of the various machines for the wet and dry preparation of clays is traced, the principles underlying the preparation and disintegration of clay, rather than the operation of individual machines or groups of machines, being dealt with. In general, present-day methods represent a combination of the use of modern mechanical appliances and the old-fashioned clay weathering process, now largely mechanized. [P]

1830. **New Designs in Brick Making Machinery.** SPINGLER, K. *Progressus*, 1953, 5 E.3, 17–9. Of the fifteen types of equipment illustrated, three are preparation mills: (1) a toothed roll crusher for flint clay; (2) edge-runner mill (twin runners); (3) rolling mill. A 'fermenting' mixer for use between the pan grinder and finishing rolls is also illustrated.

1831. **Preparation of Alumina Ware.** STOTT, V. H. *Metallurgia, Manchr.*, 1951, **44** (264), 212. Describes grinding methods for preparation of alumina slip. Ball mills are generally used but micronizers have been used alone or in combination with ball milling. Wet and dry milling appear suitable. Comments are made on the series of

articles in recent months where various techniques used at R.A.E., British Ceramic Research Association, N.P.L., and Leeds University are described.

1832. **Developments in Clayworking Machinery.** SYKES, L. J. *Trans. Brit. Ceram. Soc.*, 1939, **38**, 378. The paper includes notes on the use of high-speed rolls. The modern trend is to use these for the fine grinding of clays for tiles, or clays containing limestone.

1833. **Grinding of Ceramics.** TAGGART, A. F. *Handbook of Mineral Dressing*, 1945. Wiley & Sons, New York, Chapman & Hall, London. Sect. 6: 1, 6, 13. The mills specially adapted for the grinding of ceramics are described briefly.

1834. **Particle Size Distribution and Mechanism of Size Reduction.** TANAKA, T. *Chemical Engineering, Japan*, 1955, **19**, 152–7; *Chem. Abstr.*, 1955, **49**, 8575. *See under* Fundamental Aspects and Size Distribution.

1835. **Modernizing Dry Kaolin Milling in South Carolina.** TYLER, P. M. *Engng Min. J.*, 1949, **150** (6), 56–8. The first stage in processing dry milled kaolin is the shredding process. This is done in a pan mill without runners. Numerous knives protrude upwards from rectangular slots, and the shavings pass through the slots for drying and further disintegration. Illustrations of the Clay Slicer.

1836. **Particle-Size Distribution in Some Ground Ceramic Raw Materials.** VIEWEG, H. F. *J. Amer. ceram. Soc.*, 1935, **18**, 25. Experiments were carried out on typical commercial flints and felspars, analyses being made on three batch-ground felspars, two continuous-ground felspars, two batch-ground flints, and three continuous-ground flints. The batch-ground materials were found to have particle-size distributions in the range above 5 microns, characterized by an inverse fourth power size-frequency. The continuous-ground materials had more complex particle-size distributions, which are related to those of the batch-ground materials. [P]

1837. **Particle Size Measurement of Kaolin and other Clay Materials.** VINTHER, E. H. and LASSON, M. L. *Ber. dtsch. keram. Ges.*, 1953, **14**, 259–79. *See under* Particle Size Measurement.

1838. **Preparation Machines in the Brick Industry.** WELZEL, G. *TonindustrZtg*, 1941, **65**, 285. The quality of brick production and its economical manufacture are largely dependent on the preparation of the raw material, and faults in manufacture are found to be mainly in the preparation and not in the presses. The methods of preparation, the effects of the equipment used and best design of feeders are discussed in detail.

1839. **The Design and Correction of Dies. Part II. Particle Size and Grinding Method as Factors in Die Control.** WHITAKER, L. R. *Brick·Clay Rec.*, 1945, **106** (4), 42; *Brit. Clayw.*, 1949, **57**, 291. The effect of the particle size of a mix on the manufacturing processes is discussed, and a good screen analysis of shale is given as an example. The factors to be taken into consideration for the correct size distribution of material ground by means of dry pans, roll grinding and hammer mills are explained. The author emphasizes the need for excess grinding capacity, and deals with the problems of obtaining a uniform mixture from the non-uniform ground materials. It is better for the circulating load to be kept at a low level to avoid wasting power, and full use should be made of machinery to reduce the manpower required.

1840. **The Manufacture of Bricks in South Africa.** WILLIAMS, A. H. *J. Instn cert. Engrs, S. Afr.*, 1947, **20** (3), 78. The general process of brickmaking is outlined on the basis of current practice at a brickworks at Springs in Transvaal. An improved perforated pan edge-runner is described; by using radial, rather than circumferential, slots in the pan bottom clogging is prevented and the output is increased 30%. Oversize is fed to a hammer mill, which can deal hourly with 15–20 tons of material containing 10% of moisture; if dry clay is fed to the hammer mill, 30 tons can be ground per hour. 10 figs. [P]

1841. **Significance of Particle Fineness and Size Distribution and the Composition**

of Clays in the Production of Heavy Ceramic Products. WINKLER, H. G. F. *Ber. dtsch. keram. Ges.*, Oct. 1954, **34**, 337–43. The particle characteristics are of outstanding importance in the production of bricks, etc., both as to size distribution, shape and nature. The methods of analysis (sieving and pipette methods) are described and results are presented in a series of 14 graphs. Recommendations are made for preparation of various products.

1842. **An Interesting New Grinding Process.** WOLFRAM, H. G. *Bull. Amer. ceram. Soc.*, 1939, **18** (10), 374–5. Description and application to clay of the "micronizer", a new concept.

1843. **Modern Grinding Methods in California.** WRIGHT, J. *Ceramic Ind.*, 1924, **2**, 207. The plant of the American Grinding Co., at Los Angeles is described. The raw materials are conveyed to a chrome-steel jaw crusher, which will crush clay, flint and spar alternately as required. The crushed material, in pieces $\frac{3}{4}$ in. in diameter and smaller, is elevated to 100-ton bins, from which it is fed continuously with a constant volume of water, into a Hardinge mill measuring 8 ft × 22 in. The fines produced in this mill are carried out with the overflow, and are then pumped into a small hydro-separator (Dorr Thickener). Dr. Heinecke, a former Director of the State Porcelain Works, Berlin, proceeds in a similar manner (*German Pat.* 339339).

CHALK AND LIMESTONE

1844. **Chalk Crushing and Screening Plant.** ANON. *Cement & Lime Manuf.*, 1953, **26** (4), 57–9; *Cement Lime & Grav.*, Jan. 1953, 304–7. A new plant by Chalmers Engineering Works at the quarries of the Chinnor Cement & Lime Co., Ltd., is described. The chalk is crushed in a single toothed roll crusher at 70 tons per hour, and at sizes of 36 × 24 in. Details of screens and conveyors are given. Diagrams.

1845. **The Manufacture of Nitro-Chalk.** ANON. *Industr. Chem. Mfr.*, 1954, **30** (3), 107–10. The mill operates in a closed cycle, the product being pneumatically transported to the ammonium nitrate treatment plant for the manufacture of nitrochalk. The crushing process is controlled to interlock with the other plant operations. The type of 'pulverizer' is not stated.

1846. **Chalk Crushing and Screening at Chinnor.** *Sci. Art. Min.*, Jan. 1953, **63**, 176–7. Feed of 36 × 24 × 24 in. is reduced by a Fraser and Chalmers manganese steel tooth roll crusher 30 in. diameter by 50 in. long.

1847. **Open Circuit Crushing is Effected in Stilfontein Reduction Works.** *S. Afr. Min. (Engng) J.*, 1952, **63** (2), 629–31. First stage is by rod mills, which do not appear very sensitive to feed size. The sorting and crushing is described in detail.

1848. **Limestone Quarrying.** EVANS, A. G. P. and WHITNEY, F. R. *Road Tar*, 1950, **4** (1), 5–7. Considers the operations (1) blasting, (2) further blasting, (3) loading to crushing plant, (4) crushing for road aggregate.

1849. **Scientific Problems in Chalk Grinding.** HUTTIG, G. F. *TonindustrZtg*, 1953, **77** (21/22), 365.

1850. **Particle Size Distribution of Hydrated Lime.** JOGLECAR, G. D., KUMARASWAMY, M. P. and BHUKAR, V. M. *J. Sci. industr. Res.*, 1953, **12** (11), 343–5. Impurities segregate with the larger particles. Quality is improved if these are removed. A sedimentation method is described for doing this.

1851. **The Hydration of Lime.** LOMAS, J. *Int. chem. Engng*, 1951 (5), 213–5. The grinding of quicklime is described by a ring roll mill, ball mill and hammer mill to give uniform-sized products $\frac{1}{8}$–2 in. depending on requirements. There are conflicting views upon the need for very fine grinding of quicklime before hydration, but for the sugar-beet industry a fineness of 200 mesh is required, which is achieved by a ball mill with air separation.

1852. **Primary Crushing: Progress Report No. 3.** SHEPPARD, M. *Rep. Invest. U.S. Bur. Min.*, No. 3390, 1938. This report deals with the relationship between feed and product of two different limestones, as to size distribution and particle shape, when crushed in the same crusher.

1853. **Triple Production with Improvements.** SWANSON, H. E. *Rock Prod.*, 1947, **50**, 103. By installing primary crushing and screening equipment in the quarry of a limestone plant, and conveying the material by belt to the factory, output has been considerably increased. A diagram illustrates the flow of material through each operation. Four bucket excavators are used to win the material, which is transported from the primary to secondary crushers by 10-yd tipping lorries.

1854. **Impact Primary Produces Cubical Products.** TORGERSON, R. S. *Rock Prod.*, 1945, **48** (11), 66. Dolomitic limestone is fed into a hopper equipped with a vibrating feeder which maintains a steady input to a double impeller crusher. In this machine two large impellers are operated clockwise and counter-clockwise by electric motors, with the tops of the impellers running away from each other. Rock is struck by the impeller bars which travel at speeds varying from 300 to 900 rev/min. This machine acts as a primary crusher, taking stone up to 30 in., and can handle up to 100 tons per hour. Throughs are elevated and screened. The fraction -1 in. $+\frac{1}{8}$ in. goes to a surge bin, and the fraction $-\frac{1}{8}$ goes direct to a bin for lorry loading. A slotted $\frac{1}{8}$-in. screen is used to get maximum screening production, and as the crusher product is cubical in shape, there is no trouble from slivery particles with this type of screen.

1855. **Occurrence, Properties and Preparation of Limestone and Chalk for Whiting.** WILSON, H. and SKINNER, K. G. *Bull. U.S. Bur. Min.*, No. 395, 1937.

1856. **Push Button Controlled Fine Grinding in a Limestone Plant.** Rod Mills. WRIGHT, C. E. *Rock Prod.*, April 1955, **58**, 88–9, 186. A completely mechanized and electrified plant at Dolomite Products Inc., Ocala, Fla., produces 40 tons per hour of finely-ground limestone, using a rod mill with an oil-fired furnace supplying warm air for drying. The rod mill is 6 ft × 12 ft with 3-in. diameter rods and a 200-h.p. motor.

COAL AND COKE

1857. **Coal Pulverization,** *see also under:* General Papers; Mechanism of Fracture; Size Distribution; Grindability; Non-Mechanical Methods of Pulverization; Hammer Mills.

1858. **Physical Studies of Coal. Rep. Dep. sci. industr. Res., Lond.**, 1951–2, p. 112. H.M. Stationery Office. A series of field tests on an industrial pulverizer, undertaken in collaboration with the British Coal Utilization Research Association, has confirmed the conclusions of pilot trials and when fully analysed should enable comparisons of the different coals and of the influence of grinding mill variables. The tests so far indicate that the present grindability index is not entirely satisfactory, and further field tests are envisaged with different types of mill. The trials have shown the necessity of a knowledge of the fundamentals of coal structure and the mechanism of breakage. Static and dynamic laboratory tests are therefore being devised. Much work has been completed which has indicated how modification of the structure of coal by pretreatment can materially alter the breakability, and grinding tests over a range of temperatures have been carried out. [P]

1859. **Characteristics of Pulverized Coal—Effect of Type of Mill and Kind of Coal.** *Rep. Fuel Res. Bd., Lond.*, 1934, p. 117. H.M. Stationery Office. High-speed air-swept impact mills tended to produce a high proportion of coarse particles and also rounded particles. Generally there is a wide variation in shape; tube mills produced flake-like aggregates of fines and a more even distribution of ash. Bright coal tended to be more concentrated in the finer fraction and dull coal in the coarser fraction. [P]

1860. **Resistance of Coal to Grinding.** *Rep. Fuel Res. Bd., Lond.*, 1936, p. 49. H.M. Stationery Office. The energy required to produce unit surface increase was determined by several methods and the compression method was found to require least energy. Two anthracites, one fissured, were submitted to the U.S. Ball Mill Standard Test. The fissured structure had a greater effect on the coarse crushing characteristics. The efficiency of grinding in terms of surface area produced was the same whether single stage or 10% cycles were employed.

1861. **Resistance of Coal to Grinding and Crushing.** *Rep. Fuel Res. Bd., Lond.*, 1937, p. 42, H.M. Stationery Office. Two South Wales coals were submitted to compression tests on different size cubes, jaw crusher tests, crushing roll and ball mill tests. As the size of cubes decreased the strain energy at fracture increased (in compression tests). The same tendency was shown in jaw crusher tests. Both crushing roll and ball mill tests showed increased resistance as fineness increased. The size distribution curves were polymodal (more than one predominant size). The secondary mode always occurred at about 1 mm and 0·4 mm respectively for the two coals, irrespective of the intensity of crushing.

1862. **Gas.** *Report of the Productivity Team to U.S.A.*, 1952. British Productivity Council, London. Coke Ovens, p. 29. Every undertaking regarded the fine crushing of the determined blend of coal as a necessity for the attainment of the specified and constant bulk density. The desirable fineness of 80% (or 85%) passing a ⅛-in. mesh was produced by first breaking in a Bradford breaker and then reducing in a Pennsylvania hammer mill. To maintain a constant bulk density it was common practice to spray a heavy fuel oil or waste wash oil on to the blended coal mixture at the entrance to the hammer mill. From 0·1 to 0·25 gallon per ton was used according to moisture content (varying from 5% to 8%). 50 lb/cu. ft was the bulk density usually achieved.

1863. **Characteristics of Pulverized Coal—Effect of Type of Mill and Kind of Coal.** *Pulverized Fuel Conference*, 1947. Institute of Fuel. 2 gns. Summary of Conclusions of *Tech. Pap. Fuel Res., Lond.*, No. 49. Six types of mill were used: tube, lab. ball mill with no air sweeping, slow-speed ring ball mill, medium-speed emery mill—no recirculation of oversize, hammer and pig mill—with high-velocity air sweeping and recirculation. Five coals were used. Conclusions were as follows. (1) Fineness. Ball ring mill and emery mill gave particle size and size distribution nearly identical and independent of coal type. Size distribution was close to R. and R. law. The other mills gave large variation in size distribution, including coarser product. The tube mill gave agglomeration with flakes, high-speed impact mills gave agglomeration due to classifier action and more with harder coals. The difference between mills and coals was accentuated as product fineness increased. (2) Particle shape. Tube mill gave agglomerated superfines, some also from ball mill. High-speed impact mills gave rounded particles. Difficult to distinguish particles from each mill. (3) Ash Distribution. Tended to concentrate in the coarser fractions except for tube mill, where the distribution was even. Other distribution data are given. (4) Banded Constituents. Variation in distribution among coarse and fine fractions. *See under* Berckel, Brown, Handscombe, Hawkesley, Morland, Wilkins and Wilson. [P]

1864. **Coal Preparation.** 4th World Power Conference, London, 1950. *See under* C. Wilwertz and W. Idris Jones.

1865. **Resurfacing Pulverizer Rollers.** ANON. *Engineering, Lond.*, 17 Aug. 1956, **182** (4719), 214–15. Rebuilding the rolls of coal pulverizing mill was done until 1948 by hand welding as many as five or six times before the rolls were scrapped. A disadvantage is the time occupied and the development of cracks. A solution has been found, by the Metropolitan Vickers Co., Ltd., in the form of an automatic welder where a preheat of the roll to 400°C does not affect the welder, and where the time of deposition is reduced by 80%.

1866. **Grinding Coal.** *Financial Times*, 29 July 1955, p. 11. Investigations by the Fuel Research Station, D.S.I.R. and the British Coal Utilization Research Association jointly with a number of pulverizing mills have shown that the efficiency of grinding is not solely related to power consumed but is also dependent on the control settings of the mill used. As a result, equations have been developed for coals of different Hardgrove grindability indices which relate the fineness and rate of grinding to the control settings of the mill. It has been demonstrated that increased spring loading on the grinding elements will increase output. [P]

1867. **Symposium on Coal Preparation.** Leeds University, Dept. of Mining, No. 1952; *Fuel. Abstr.*, Oct. 1954, 3391. *See under* L. W. Needham.

1868. **Apparatus for Pulverizing Coal and Coke.** ANON. *Tonw.-Ofen u TöpfZtg*, 1918, **42**, 18. A general description without illustrations.

1869. **Steam Jet Pulverizer.** ANON. *Steam Engr*, 1946–47, **16**, 432–3; **17**, 71–2; *Heat. & Ventilating*, Feb. 1947, **44**, 87. The Blaw Knox Co. has produced a pulverizer using a steam jet (Superheat) at 750°–900°F and 100 lb/sq. in. The product is delivered to the burners either direct or after separation of the steam. Capacities up to 10 000 lb/h with solid fuels of various kinds. An electric eye at the burners ensures shut off of supply on ignition failure.

1870. **Method of Test for the Grindability of Coal by the Hardgrove Machine Method A.S.T.M. Design D. 409–51.** *Book of A.S.T.M. Standards*, 1955. Pt. 5. The principle of the method is the determination of the amount of a 50-gram sample passing a 200-mesh sieve after being ground for a specified number of revolutions in a ball race pulverizer of specified design. The grindability index is defined as $13 + 6{\cdot}93\,W$, W being the weight in grams passing the 200-mesh sieve. The index was formerly based on the surface area of the whole of the sieved product which was compared with that of a standard coal. Details of the tentative methods are given in the earlier books of standards. *See* Hardgrove, *Trans. Amer. Soc. Mech. Engrs*, 1932, **54**, 37–46; Taggart, *Handbook of Mineral Dressing*, 1945, Sect. 19, 97–8; *Proc. Amer. Soc. Test. Mater.*, 1935, **35** (1), 854; and *Combustion Appliance Makers' Association Document*, No. 1657, 1938, 57–64.

1871. **Tentative Method of Test for Grindability of Coal by the Ball Mill Method. ASTM Design D.408–37T.** *Book of A.S.T.M. Standards*, 1949, pt. 5, pp. 616–19. The principle of the method is the determination of the number of revolutions of a ball mill required for grinding a specified weight of crushed coal until 80% passes a 200-mesh sieve. *See* Yancey, Furze and Blackburn, *Trans. Amer. Inst. min. (metall.) Engrs*, 1934, **108**, 267, Estimation of the Grindability of Coal. For the modified method (no replenishment), *see* Hertzog, *et al. Tech. Publ. U.S. Bur. Min.*, No. 611, 1940. This tentative method of test has been deleted since 1949.

1872. **Grindability Indices. Numerical Comparison.** *Combustion, N.Y.*, 1940, (5), 31–4. The values below are embodied in a graph in the above paper. *See also* Brunjes, Grindability.

Ball Mill D408–37.T.	Hardgrove D409–37.T.		Ball Mill D408–37.T.
20	29	20	14
30	43	30	21
40	56	40	28
50	68	50	36
60	80	60	44
70	90	70	52
80	100	80	60
90	110	90	70
100	118	100	80
		110	90

The index 100 on the ball mill scale signifies the softest and most easily ground material. The index on the Hardgrove scale is a standard reference figure.

1873. **Drop Shatter and Tumbler Tests for Coal.** *Book of A.S.T.M.· Standards*, 1955, Pt. 5. Method of Test for Drop Shatter Test for Coal A.S.T.M. Design. D.440–39 pp. 992–6. Method for Tumbler Test for Coal. A.S.T.M. Design D.441–45, pp. 997–1000.

1874. **Sampling and Fineness Tests.** *Book of A.S.T.M. Standards*, 1955, Pt. 5. Standard Method of Sampling and Fineness Test of Powdered Coal. A.S.T.M. Design. D.197–30, pp. 982–5. Standard Method of Test for Screen Analysis. A.S.T.M. Design D.410–38, pp. 1001–3. Standard Method for Designating the Size of Coal from its Screen Analysis. A.S.T.M. Design D.431–44, pp. 1004–5. Standard Method of Test for Size of Anthracite. A.S.T.M. Design. D.310–34, pp. 1006–8.

1875. **Report on 2nd International Conference on Coal Preparation. Essen.** Sept. 1954. *Ann. Min. Belg.*, Jan. 1955 (1), 49–67; *Fuel Abstr.*, June 1955, 5058.

1876. **Steam Jet Coal Pulverizer.** *Blast Furn.*, 1947, **35**, 470–2.

1877. **Du Pont Tries New Route to Synthesis Gas.** ANON. *Chem. Engng*, Mar. 1954, 114. Du Pont will be pulverizing its coal in fluid energy mills using steam as the high-velocity fluid. This is prior to combustion in steam and limited oxygen in a modified steam-tube boiler with slagged ash.

1878. **Degradation of Coal.** *Coal Age*, 1936, **41**, 309–10. A summary of information on this subject presented to the annual meeting of the Illinois Mining Institute. Contributions by C. M. Smith, L. A. Hill and I. W. Starks.

1879. **Two Coal Products from a Single Roll Crusher.** ANON. *Edg. Allen News*, 1946, **25**, 713–14.

1880. **Plant for Pulverizing Coal.** *Edg. Allen News*, Jan. to July, 1955, **34**. The British Rema ball mills and ring roll mills are described. General consideration concerning choice of equipment is briefly outlined. The ball mill is designed for large outputs, 8–10 tons per hour. The ring roll mill, fitted with a vacuum system, is designed for coals and a large number of other materials. The feed is assisted by the suction generated by the fan at the mill outlet, tramp iron, etc., falling out. An illustration shows a ring (3) roll mill the ring being vertical. Wear of components does not affect the fineness of grinding. A plant for firing a cement kiln consists of an air-swept ball mill from which fines are led to the firing end of the cement kiln. Illustration. The output is 4 tons per hour of fuel, 90% passing a 170-mesh sieve. Fan design and distribution to burners. The construction features of fans are described in detail. Wear problems are dealt with. Power consumption, burners, filters, cyclones and conveying equipment are briefly described. Table of data on the British Rema ring mill is given. Table of Sizes and capacities of the British Rema ball mill pulverizing equipment, central shaft driven and trunnion types. Description of Rema tube mill with air classifier; British Rema ring roll plant with air cleaning plant. (Vertical ring with three rollers, the top roller being driven, all three being pressed against the inside of the ring.) Coal is ground to 90% passing 200 B.S.

1881. **A Pneumatic Pulverizer Mill.** *Engng Boil. Ho. Rev.*, Aug. 1952, **56**, 92–7. A short résumé of the work of Russian investigators into the action of pneumatic mills for projecting coal against a baffle plate. The critical air speeds are from 30 to 50 ft/s for different coals, but higher velocities would be required according to circulation ratio. Several installations in Russia and Germany are described. It is claimed that a coking coal can be ground to 28% through 88 microns for 36 kWh/ton at 1300 lb/h output.

1882. **Some Novel Methods of Coal Pulverization.** *Engng. Boil. Ho. Rev.*, 1946, **61**, 147–53. Description of the German-built 'Angers' pneumatic pulverizer. Description of development, design and operation of coal atomizer.

1883. **Test of a Reported Effect of Pulverization upon Carbonization Properties of Coal.** *Fuel, Lond.*, 1952, **31**, 33–6.

1884. **Measurement of Coal Grindability.** *Fuel, Lond.*, 1955, **34** (3), 367. A Hardgrove-type machine has been designed and manufactured by H. W. Wallace & Co., Ltd., for measuring the grindability of coal to be used as pulverized fuel. The machine conforms to A.S.T.M. Tentative Standard D.409–37T in handbook D.5, and has been planned at the suggestion of British Coal Utilization Research Association to accommodate any minor changes in the test which may be found desirable. The 'bowl' or container is a unit complete with pestle and balls, which can be removed and dismantled for cleaning. For test, a load (standard) of 64 lb is applied. The pestle is rotated at 20 rev/min for exactly 60 revolutions, the machine stops automatically for examination of the contents.

1885. **Swing Hammer Pulverizers.** Equipment in the Vanderbijl Coke Oven Plant in South Africa. *Iron Coal Tr. Rev.*, 1947, **155**, 1048.

1886. **Coal Breaking to Size.** ANON. *Min. Mag., Lond.*, Dec. 1946, **75**, 360–1. The history and development of coal breakers are briefly reviewed and details are given of a British machine embodying two groups of picks and a reciprocating conveyor.

1887. **Coal Crushing Equipment. Installation and Application.** ANDERSON, J. W. L. *Iron Coal Tr. Rev.*, 1938, **136**, 405–7. Description of breakers and systems for crushing coal. Illustrations of hammer crushers (knives or hammers fitted to heads revolving against breaker plates).

1888. **A Microscope Study of Pulverized Coal.** ANDREWS, L. V. *Mech. Engng, N.Y.*, 1925, **47**, 429.

1889. **Increase of Surface and Expenditure of Work in Crushing and Milling of Solid Fuels.** ANSELM, W. *Zement-Kalk-Gips.*, 1953, **6**, 15–22.

1890. **The Grindability of Coals Mined in the United States, Canada, and other Countries.** BABCOCK & WILCOX Co. Brochure, 1936.

1891. **Improvements in Controllers for Maintaining Proportionality or Substantial Proportionality between the Variations of a Pair of Variables.** BABCOCK & WILCOX, LTD. *Brit. Pat.* 717363, 1952/54. An electronic arrangement is shown for maintaining a constant relation or a desired relation between, say, quantity of coal leaving a pulverizer and the quantity of gas passing through. The pressure differential is the measure of the quantities.

1892. **A Method of Rating the Grindability of Coal.** BALTZER, C. E. and HUDSON, H. P. *Can. Min. Br., Rep.*, No. 737–1, 1933. *See under* Grindability.

1893. **The Plastic Deformation of Fine Particles of Coal and Other Materials.** BANGHAM, D. H. and BERKOWITZ, N. *Coal Research*, Dec. 1945, 139–50 (*Coal Research* is issued by the British Coal Utilization Research Association). *See under* Mechanism of Fracture.

1894. **Breakage of Lump Coal.** BANNISTER, H. and WHELAN, P. F. *Colliery Engng*, Mar. 1955, **32**, 117–9. Breakage tests are described which show a reduction in size degradation of lump coal when dropped into a shallow pool of water.

1895. **Friability of Coal.** BASSETT, H. N. *Engng Boil. Ho. Rev.*, 1937, **50**, 888–90. Tests on friability by the Canadian Dept. of Mines and the applications to coals of various friabilities are discussed.

1896. **Explosions in Coal Pulverizing Mills.** BECHDOLDT, H. *Mitteilungen Vereinigung Gross-kesselbesitzer*, July 1954, **29**, 172–4; *Fuel Abstr.*, Nov. 1954, 4306.

1897. **Broken Coal.** BENNETT, J. G. *J. Inst. Fuel*, 1936–7, **10**, 22–39. The importance of a study of coal size is pointed out, and methods for an exact study are described. Considerable experimental evidence is put forward to confirm the applicability of the Rosin–Rammler function as the simplest one to represent the distribution of sizes

below about 3 in. The law is valid for various types of product, e.g. washed slacks and products of hammer crushers, and the range of validity to the whole colliery output is discussed. By applying the formula to all collieries, it is possible to determine the sizing of the total input of coal in any district. In an appendix, the theoretical basis of the R and R law is discussed, and given a theoretical foundation based on a study of the fracture of a brittle material, breaking at pre-existing cracks, and on Poisson's law of small numbers. The significance of the Rosin numbers n and $\bar{x}$ is pointed out, the method of graphical treatment of sieving results using the R.R. function is described. Between the extreme cases of a Gaussian distribution, n being high, and the Rosin distribution, there is the sizing of graded coals, and it will be of great interest to find a law intermediate between the two distributions, which would serve to define the size characteristics of graded coal. 24 graphs, 7 tables, 88 refs.

1898. **The Preparation and Firing of Powdered Fuel at Colliery Maurits of the State Mines, Limburg, Holland.** BERCKEL, F. W. von. Pulverized Fuel Conference, 1947, 528–35. Institute of Fuel. 2 gns. Includes the steel and power consumption of the Fuller-Lehigh ball mills (pusher type) with cyclone separation, for coal pulverization. (These mills are now obsolete.) [P]

1899. **Investigation of Procedure for Determining Coal Grindability by the Ball Mill Method.** BLACK, C. G. *Trans. Amer. Inst. min. (metall.) Engrs*, 1936, **119**, 330. The details of sampling preparation and of testing procedure are discussed. The errors in shortening the test are pointed out, and suggestions are made for interpreting the results.

1900. **The Compressive Strength of Coal.** BODE, H. *Glückauf*, 1933, **69**, 296. Concerns chiefly the petrological distribution of the constituents of the different size fractions. The compressive strength of high-durain coals is greater than for high-vitrain coals.

1901. **Standard Grindability Tests Tabulated.** BOND, F. C. *Trans. Amer. Inst. min. (metall.), Engrs.*, 1949, **183**, 313.

1902. **A Two Stage Phenomenon in the Breakage of Coal.** BOND, R. L. *Fuel, Lond.*, April, 1954, **33**, 250. *See under* Mechanism of Fracture.

1903. **Similarities in the Screen Analysis of Small Coals.** BOSWELL, I. and BROWN, R. L. *Colliery Engng*, Jan./Feb. 1949, **26**, 18, 58. Laboratory tests show that repeated breakage (mild or medium intensity) yields a product which tends towards a ratio characteristic of natural smalls. The latter are characterized by a stable size distribution.

1904. **Properties of Coal Surfaces.** BRADY, G. A. and GAUGER, A. W. *Industr. Engng Chem. (Industr.)*, 1940, **32**, 1599–1604. The importance of the wetting properties of coal surfaces, and topics relating to this are discussed. Quantitative expression in terms of angle of contact, for gas and liquid, is put forward.

1905. **The Graphic Representation of Size Distribution.** BRAUKMANN, B. *TonindustrZtg*, July 1954, **78** (13/14), 213. Verein Deutsche Ingenieur Conference, Staubtechnik, Bad Kissingen, 1954. *See under* Fundamental Aspects (Size Distribution).

1906. **Pulverizer Apparatus.** BRITISH THOMSON-HOUSTON CO., LTD. *Brit. Pat.* 645146, 1950; *Chem. Abstr.*, 1951, 1557. Pulverizing by metallic particles thrown against coal from rotating impeller at high velocities, or by compressed-air firing of coal and metallic particles at an anvil. Centrifugal or magnetic separation.

1907. **Coal Breakage Processes. I. A new Analysis of Coal Breakage Processes. II. A Matrix Representation of Breakage.** BROADBENT, S. R., CALLCOTT, T. G. *J. Inst. Fuel.*, 1956, **29** (191). Previous approaches to the analysis of coal breakage processes are briefly discussed and the concepts underlying a new method of analysis are presented. This is a matrix method and its application to broken coal is described. In the analysis of coal breakage, size distributions are described by vectors. Processes which alter size distributions such as breakage and size classification are represented by

matrices multiplying the vectors. Complex processes may be analysed by simple mathematical procedures when matrices are used. A particular form of breakage in which the particles of every size have an equal probability of being selected for breakage are discussed in detail. Information is supplied which is essential for the computations made in subsequent papers. The concept of selection and breakage functions is developed. 13 refs.

1908. **Coal Breakage Processes. III.** Broadbent, S. R., Callcott, T. G., Scott, W. *J. Inst. Fuel*, Jan. 1957, **30** (192), 13–17. In the coal transport system investigated, undesirable breakage has been occurring. The extent of breakage at different points in the system were found by matrix analysis, although by shatter test the strength of the coal remained unimpaired throughout the system. Remedies were suggested.

1909. **Unit Operations.** Brown, G. G. and Associates. 1950, J. Wiley & Sons, New York, Chapman & Hall, London. On p. 31 is an illustration of a Bradford breaker. Coal is broken by tumbling inside a cylinder, whose periphery is a screen, and provided with lifters. Unground material passes out at the end of the cylinder.

1910. **The Relative Grindability of Coal. The S.C./U.A.L. Grindability Test.** Brown, J., Ivison, N. J. and Birney, J. W. Report. Pulverized Fuel Conference, Harrogate, 1947. Institute of Fuel. 2 gns. *See under* Grindability.

1911. **Broken Coal, 3. Generalized Laws of Size Distribution.** Brown, R. L. *J. Inst. Fuel*, 1941, **14**, 129.

1912. **Bibliography of Literature on the Breaking and Sizing of Coal.** Brown, R. L. and Hawksley, P. G. W. *Brit. Coal Util. Res. Ass., Document* C/3103, 1944. About 300 references relating mostly to fundamentals and to breakage of large coal.

1913. **The Size and Strength of Coal.** Brown, R. L. *Trans. Instn Min. Engrs, Lond.*, 1944, **103** (3), 88. The relation with pre-existing cracks is discussed with reference to methods of breaking coal. Analysis of screen data by means of non-dimensional ratios is proposed.

1914. **The Brittle Fracture of Precracked Solids.** Brown, R. L. *Research, Lond.*, 1947, **1**, 93. A theoretical consideration of the fracture of pre-cracked solids is shown to suggest a relation between shatter strength of equal-sized lumps and the sieve analysis of the consignment from which the lumps are taken. Experimental evidence obtained with a friable coking coal is given in support.

1915. **The Screen Analysis of Washed Small Coals.** Brown, R. L. *Colliery Engng*, 1948, **25**, 420. The only difference between washed and natural coals is the removal of the finer sizes.

1916. **The Fracture of Solids. III. Random fracture of solids and natural frequency distributions.** Brown, R. L. *Metallurgia, Manchr*, 1949, **39**, 277. The fracture of coal is discussed in relation to size distribution of fragmented pieces. When size distribution of broken coal deviates from natural distribution further rough handling of a consignment promotes natural size distribution. In the case of coal, strength measurements are made by a shatter test and the strength is calculated from the resulting degradation.

1917. **International Conference on Coal Preparation, Paris, June 1950. A Review of Conference Papers.** Brown, R. L. *Mon. Bull. Br. Coal Util. Res. Ass.*, 1950, **14** (7), 255–65. About 60 papers are included in the review. The author presents the main features in the breakage of coal. The papers are published in *Rev. Industr. Min.*, 1950–51, **31**, 1–900. The conference was sponsored by the Centre d'Etudes et Recherches des Charbonnages de France, Paris.

1918. **A Description of the Breaking of Coal.** Brown, R. L. *Rev. Industr. min.*, 1950–51, **31**, 615–30; International Conference on Coal Preparation, June 1950, Paris. Coal varies widely in breaking strength even in one consignment. Size analysis studies

of fragmented material show that repeated handling leads towards a stable size distribution. When breakage is determined by microstructure, a relationship with rank of coal emerges. Suggestions are made for overcoming difficulties in the study of the effect of cracks and flaws. Measures to expedite application to practice of present fundamental knowledge of coal breaking are discussed. It is pointed out that in a coal-breaking machine, two modes of breakage may occur, and that these may not depend in the same way on the rank of coal. 22 refs.

1919. **Physics of Coal. Problems of Breakage and Structure.** BROWN, R. L. *Times Science Review*, Winter, 1953, pp. 13–14. After a general introduction, the report considers the subject under the following headings: (1) size grading; (2) size distribution; (3) coal structure; (4) descriptive model of a precracked solid; (5) controlled breakage; (6) energy considerations; (7) simple crushing; (8) complex crushing; (9) dynamic testing; (10) mill mechanisms.

1920. **Some Experiences of Pulverizing Coal.** BROWN, R. L. and HURLEY, T. F. Fifth World Power Conference, Vienna, 1956, Sect. C, Paper 116 C/8. Obtainable from World Power Conference, Trafalgar Square, London. The paper deals with the laboratory experiments and full-scale trials with the ring ball mill ('E' mill). It is found that the performance coefficient is a function of the Hardgrove index of the coal. Hence this test can be regarded as one of the main criteria to be used in assessing the value of a particular coal for pulverizing in a type E mill. The limitations imposed are described, but there is a strong indication that experiments of a similar nature on other mills may be of help in attaining the ultimate objective of deciding the allocation of coals for pulverizing. [P]

1921. **The Designation of the Fineness of Pulverized Brown Coal.** BULL, F. A. *J. Inst. Fuel*, 1955, **28** (4), 163–70. A satisfactory means is sought for specifying the fineness of samples of brown coal prepared for briquetting. The use of the specific surface is proposed for this purpose and a rational formula is derived for calculating the extent of this surface from the sieving analysis. The experimental and theoretical difficulties involved in applying this method are discussed and alternative means sought which might be more satisfactory for characterizing the size degradation of the coal. The size distributions of some of the samples are shown to follow the Rosin–Rammler law reasonably well, but there are practical and mathematical limitations to the use of this equation for the purpose of estimating the specific surface. It is concluded that a precise and accurate estimate of this property of a comminuted system cannot be obtained from the screening analysis by mathematical methods when a proportion of the particles lies below the sieving range. Furthermore, it is pointed out that the size distribution of a particulate material cannot be completely specified by means of a single parameter: at least two are required and even these are inadequate unless the distribution closely fits a known mathematical law. Nevertheless, the formula described herein may be useful for estimating the specific surface of coarse aggregates coming entirely within the sieving range. The proposed specific-surface parameter is easily calculated and can be obtained whether or not the size distribution follows a known mathematical law. For the above reasons the specific surface has not been used to designate the fineness of the pulverized samples of brown coal. Nevertheless, it is often an important property in a comminuted system. The specific-surface parameter proposed by the author has been explained because it may be of use when handling crushed or broken substances which do not contain any particles finer than the finest sieve. Apart from this restriction the proposed parameter can be applied to practically any sort of size distribution; its other chief advantage is that it is very easily calculated from the sieving analysis if a suitable series of screens has been chosen. 11 refs.

1922. **Coal Grindability. A Standard Procedure and a Survey of Grindabilities of British Coals.** CALCOTT, J. C. *J. Inst. Fuel*, May 1956, **29** (184), 207–17. The standard procedure used by the British Coal Utilization Research Association for determining the grindability of British coals with the Hardgrove machine is described in detail.

The index is expressed by the percentage of ground product that passes a 200 B.S. sieve. It may range from 2% to 30%. Strict adherence to the procedure maintains the standard error of a determination at about 0·2. A survey of the grindability of British coals has been made and it is concluded that the index is a first order measure of the strength of coal. Examination of the size, distributions of the ground material for 31 coals showed that a single parameter, a distribution coefficient, is sufficient to define the percentage of the particles smaller than any size between 76 and 300 microns. The accumulative distributions are assembled in a graph and the detailed data for the coals tested and tabulated. 6 refs.

1923. **Coal Grindability. Some Problems of Sample Preparation for Grindability Tests.** CALCOTT, T. G. *Inform. Circ. Brit. Coal Util. Res. Ass.*, 147, Dec. 1955. The paper shows that the grindability index of a coal, as given by the Hardgrove test, varies with the method of preparation even within the limits of the test specification of the test sample. Experiments show the influence of the method of preparation on the size grading and 'strength' of the sample and indicate the relative importance of these factors upon the measured grindability. The accuracy of the test in assessing industrial pulverizer performance is discussed.

1924. **Coal Preparation in Europe and Latin America.** CHERADAME, R. *Colliery Engng*, Mar. 1955, **32**, 107–9; *Fuel Abstr.*, June 1955, 5059. Preparation of Latin American coals with special reference to European practice is discussed.

1925. **A Continuously Operating Laboratory Coal Pulverizer that Measures Net Power.** COE, G. D., DELANO, P. H. and COGHILL, W. H. *Contr. Amer. Inst. Min. Engrs*, No. 127, 1942. This operates on ¾ in. or less feed in closed circuit with air separator. The construction enables the energy expended on the coal to be measured. Pulverization is by heavy roller.

1926. **Preparation Characteristics of Anthracite in South Korea.** CRENTZ, W. L. *Rep. Invest. U.S. Bur. Min.*, No. 5010, Dec. 1953, (17 pp.); *Fuel Abstr.*, July 1954, 176.

1927. **The Tube Mill in Power Stations.** DOBREFF, I., *et al. Energietechnik*, Jan. 1954, **4**, 37–40; *Fuel Abstr.*, July 1954, 178. Comparison of Russian and German data. *See* No. 1008.

1928. **Coal Preparation Progress in 1952.** DORENFELD, A. C. *Min. Congr. J., Wash.*, Feb. 1953, **39**, 109–10; *Fuel Abstr.*, Aug. 1954, 1392.

1929. **The Ultra Fine Physical Structure of Fine Bituminous Coals.** DRYDEN, I. G. C. *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1951, **15** (9), 329–39. 39 refs.

1930. **Crushing Machines for Coke and Coal Samples.** EHRMANN, K. and SPORBECK, H. *Glückauf*, 12 Feb. 1955, **91** (7/8), 187–93. Review, critical examination and comparison of crushing machines re abrasion resistance, time of crushing, power requirements, freedom from dusts, cleaning, noise, safety, design and efficiency. 19 illustrations. [P]

1931. **New Crushers for Pulverization of Coal.** FINN, W. *Erdöl u. Kohle*, 1951, **4**, 630–33. The first is a jaw crusher with very strong springs to guard against overload. The second is an impellor crusher where the size of the product is governed by the speed at which the particles are thrown against the housing.

1932. **The Gases Locked up in Coal.** FISCHER, F., *et al. BrennstChemie*, 1932, **13**, 209–16; *Fuel, Lond.*, 1933, **12**, 154. Grinding coal to less than 1·0 micron in centrifugal ball mill. *See under* Vacuum Ball Mill.

1933. **The Friability of Coal.** FISH, B. G. *Colliery Engng*, 1951, **28**, 317, 371, 413. A comprehensive review.

1934. **Pulverized Fuel Technique.** FITTON, A. *Inst. Petrol Rev.*, Jan. 1949, **3**, 18–26. A general review of present techniques in milling, burning and ash removal. Types of

mills are discussed and illustrated diagrammatically, e.g. slow-speed (ball) mills at 25–60 rev/min, medium-speed (ring roll and ring ball mills at 100–350 rev/min always with air sweeping), and high-speed mills (pin mills, hammer, beater and other impact mills) at 1000–4000 rev/min. The latter have large time and maintenance costs. The last class described is the pneumatic impact mill, which includes the "explosive" method. The excessive wear of impact plates has been countered by impinging jets of airborne coal. A normal size feed is $\frac{1}{16}$ in.

1935. **The Grindability of British Coals—A Laboratory Examination.** FITTON, A., HUGHES, T. H., HURLEY, T. F. *J. Inst. Fuel.*, Feb. 1957, **30** (193), 54–65. Grindability tests were carried out with a Hardgrove machine and a ball mill, to determine to what extent the properties of British coals affect the ease of grinding. Good correlation was obtained between the indices derived from the two machines. Only a broad relationship was found between the grindability index and the properties of the coal substance, but a closer relationship between grindability and volatile matter, carbon and hydrogen, when coking power was taken into account. Grindability indices did not differ for coals exceeding $2\frac{1}{2}\%$ in moisture content, and were not necessarily improved by cleaning the coal. Part of the power lost by not removing the fines was offset by increase in specific surface. The properties of 47 coals are tabulated in relation to their grindability indices by each method. 6 refs.

1936. **Mill Drying of Coal.** FITZE, M. E. *Trans. Amer. Soc. mech. Engrs*, May 1941, **63**, 273–6. Mill drying by means of flue gases is shown to result in improved furnace efficiency, less deposit, reduced capital outlay and costs and the practical elimination of fire and explosion hazards.

1937. **The Curved Screen of the Dutch State Mines.** FONTEYN, F. J. *Ingenieur's Grav.*, 3 Feb. 1956, **68** (5), 1–5; *Glückauf*, 2 July 1955, **91**, 781–6. A new machine for *wet* screening of fine coal. *See under* Sieving.

1938. **Pulverization Utilizes Anthracite Fines.** FRICK, C. H. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 2061, 1946. After discussing practice at Hauts Station (Pennsylvania) and elsewhere, the author shows that the horizontal mill is more reliable and less costly than a vertical mill. The capacity decreases considerably with increasing moisture content. 8 pp.

1939. **Pulverizer Performance as Affected by Grindability and other Factors.** FRISCH, M. and FOSTER, A. C. *Proc. Amer. Soc. Test. Mater.*, July, 1937, 441–6. Pulverizers, although of the same type, but of different sizes, do not rank coals alike. Laboratory grindability ratings are useful, and may be used to predict the performance of a pulverizer on a coal of known grindability without a test, but only if the relationship for the pulverizer has been previously determined by test and the effects of various modifying factors have been taken into account. A large number of coals tested by the F.W. method can now be correlated with grindabilities obtained by other methods. A table of corresponding grindabilities between the F.W. method and the Tentative methods is given. (The F.W. method is the simplified Hardgrove method, 1931. M. Frisch and G. C. Holder. *Combustion, N.Y.*, 1933, **4** (12) (June), 29; **5** (1) (July), 34.) Criticized by Calcott. The latter papers give a full appreciation of the results. [P]

1940. **Interim Report on Pulverizer Tests.** FUEL RESEARCH BOARD, D.S.I.R.—BRITISH COAL UTILIZATION RESEARCH ASSOCIATION JOINT COMMITTEE. *J. Inst. Fuel*, 1955, **38** (168), 30–6; Rep. Fuel Res. Bd., Lond., 1954, p. 39. 1955, H.M. Stationery Office. The Committee was set up in 1945 to consider available data on the relation between pulverizer performance and the type of coal used. A second object was to determine whether the grindability index of a coal could be correlated with behaviour in a commercial mill. Information on these questions might lead to the most suitable type and size of mill to be used for the type of coal predominant in a district, and to avoid the use of the wrong type of pulverizer. A Babcock and Wilcox E-type mill

(ball and ring mill) with up-draught and classifier was used. Results show strong correlation between three variables—mill power, output rate and fineness of product—for each coal. A general relation between performance and grindability index is apparent. Further tests are needed and will be made. The Hardgrove and ball mill grindability indices were used. Results are presented in tabular and graphical form. [P]

1941. **Coal Crushing in Coke Oven Plants.** Gauze, H. *Hutnik* (*Poland*), 1953, **20**, 285–88; *Fuel Abstr.*, July 1954, 177. A critical survey of the crushing equipment in Polish coke oven plants; the re-equipment necessary for the production of high-quality coke is discussed. Foreign equipment often failed to give satisfactory grinding with the harder Polish coal.

1942. **Grinding Plant Research, Parts 1–9.** Gilbert, W. *Rock Prod.*, 1931–2, **34, 35.** Several parts deal with coal grinding. *See under* No. 1092. [P]

1943. **Coal Friability Tests. A comparative study of methods for determining the friability of coal and suggestions for tumbler and drop shatter test methods.** Gilmore, R. E., Nicholls, J. H. H. and Connell, G. P. *Canad. Min. Br. Rep.*, No. 762, 1935. Seven testing apparatuses are discussed. Appendices describe the proposed A.S.T.M. tumbler and drop shatter tests for coal.

1944. **Grindability Indices of Typical Canadian and other Coals and the Relation of Grindability to Friability.** Gilmore, R. E. and Nicolls, J. H. H. *Can. Min. Br. Memo. Series*, No. 70, May 1939. An account of experiments by the Hardgrove machine method. List of results of 230 fuels, mostly Canadian coals, but a few American and Welsh anthracites. Anthracites and lignites are most difficult to grind. No definite relationship was found between grindability and friability characteristics.

1945. **Testing the Mechanical Properties of Coke.** Gobinsky, J. O. and Badanova, S. I. *Fuel*, 1937, **16**, 85. Tables of crushing-test results are presented, the method being based on calculation of sp. surface, length, width and thickness, projected areas and derived expressions.

1946. **Present Day Coal Preparation in Western Germany.** Gotte, A. *Z. Ver. dtsch. Ing.*, 21 Sept. 1954, **96**, 917–23; 1 Feb. 1955, **97**, 97–104.

1947. **Factors in Coal Selection, Pulverizing Quality and Fuel Value.** Gould, G. B. *Power*, 1930, **72**, 886–9. Various coals were tested; the effect of overloading on the fineness varied with different coals, so that two values of the grindability index 'overload' and 'under load' are used. The paper combines the grindability index (method not described), the cost of coal and thermal value, in order to determine the best coal from economic considerations.

1948. **Report of the Coal Preparation Investigations by B.C.U.R.A.** Grounds, A. *Quart. Bull. Br. Coal Util. Res. Ass.*, No. 10, 1946, 7–9.

1949. **Coal Preparation, 1950–1954. Progress Review.** Grounds, A. *J. Inst. Fuel*, July 1954, **27**, 373-7; *Fuel Abstr.*, Nov. 1954, 4301.

1950. **Limits of Grindability of Coal in Ball Vibration Mills.** Grunder, W. and Stuckmann, H. *Bergbau*, 1940, **53**, 107–12; *Feuerungstechnik*, 1940, **28**, 267. Good results were obtained at 70% ball load and 70% of the spaces occupied by coal. 12- or 15-mm balls. Further grinding after 24 hours produced coarsening.

1951. **The Random Breakage of Coal and its Assessment.** Guruswamy, S. *J. sci. industr. Res.*, 1952, **11** (11), 482–5. A method of assessing the breakage of coal is described, based on comparing the 'toughness factor' evaluated from sieve analysis of the broken product. A shatter-test apparatus is used. The toughness factor can be used in assessing the breakage under different conditions and of different coals. It is defined as the average size expressed as a percentage of the initial size of that part of

the product containing all the fines and weighing 1% of the total broken product. Data from various coals are presented in 5 tables. 6 refs.

1952. **Size and Shape of Broken Coal. 5. Rate of Settling of Coal Particles in Liquid.** GURUSWAMY, S. and ROY, L. C. *J. sci. industr. Res.*, 1953, **12B** (6), 270–4.

1953. **Shape of Coal Particles.** GURUSWAMY, S. and SRINIVASAN, S. R. *J. sci. industr. Res.*, 1954, **13B** (5), 368–9; *Fuel Abstr.*, Dec. 1954, 6278. The shape of coal particles under different conditions of breakage was calculated from volume surface area and statistical diameter of the particles. The results presented show that it is possible to give as an approximation a rectangular prism shape for the particle. The deviation from this shape is measured from the deviation in the value of the ratio of the calculated and observed surface area factors from unity. For the coal particles studied, this value lies between 0·60 and 0·98, the lower the value of the ratio, the more angular is the surface. In general, coal particles produced by fracture are more angular, thicker and more elongated than those obtained by crushing. The specific surface of coal particles estimated on the basis of rectangular prism shape will be less than the true value, depending on the nature of the breakage that the coal has undergone. For the most angular particles of coal investigated, the deviation from the true surface area was about 40%.

1954. **The Mill Unit as a High Duty Drier.** HANDSCOMBE, F. L. and MOYER, J. Proceedings Pulverized Fuel Conference, Harrogate, 1947, 747–67. Institute of Fuel. 2 gns. Traces the growth of combined milling and drying, outlines the theory of drying with heat balance calculations, and discusses the applications to coal drying. Graphical representation of performance where grinding capacity exceeds drying capacity and vice versa. Features of design necessary to avoid operating troubles. [P]

1955. **Grindability of Coal.** HARDGROVE, R. M. *Trans. Amer. Soc. mech. Engrs (Fuels, Steam, Power)*, 1932, **54**, 37–46. The need is pointed out for a method of determining the grindability of coal, and outlines a method by which new surface produced is measured in accordance with Rittinger's law. Drop-weight and ball-machine methods are described and test data are compared. A list of over 100 U.S. and Canadian coals is presented showing their grindabilities. The relation between the grindability of petroleum coke and its method of manufacture and volatile content is discussed. The Babcock ball mill runs at 20 rev/min and 50 g of coal are ground for 60 revolutions.

1956. **Size and Prepare Coal at the Mine.** HARTSHORN, S. D. *Industr. Pwr, Lond.*, July 1948, **55**, 95–6.

1957. **Mechanics of Present Pulverizing Practice.** HAWKSLEY, P. G. W. Proceedings Pulverized Fuel Conference, Harrogate, 1947, 656–87. Institute of Fuel. 2 gns. The information is collected from answers to questionnaires sent out to the electrical and cement industries, the greatest users of pulverized fuel, as to plant layout, operating conditions and abnormal occurrences. Performance data of mills in various districts are tabulated, and analysis is made of the power consumption as distributed between fan, drying, grinding and feeding. The U.S. Ball Mill Grindability Index is discussed in relation to practice. An approximate calculation of the drying capacity of pulverizers is given in a short appendix. On the basis of data provided by results to questionnaires to the cement industry and the British Electricity Authority, it appears *that the power consumption per unit output is related to the transport of material through the system rather than to the energy required to effect the size reduction process*; the latter is only a small fraction of that involved in the whole unit process of pulverizing. It is clear therefore that the pulverizing process is not so critically balanced as to be affected by differences (which may themselves be large) in the very small energies required to disintegrate the different coals. 22 refs. [P]

1958. **The Grindability of British Bright Coals—Hardgrove Tests.** HAWKSLEY,

P. G. W. *Inform. Circ. Brit. Coal Util. Res. Ass.*, No. 36, Dec. 1950. It is suggested that hardness measures an inherent property and is affected by moisture. No information on industrial suitability. The effects of physical and chemical properties are considered in detail.

1959. **Colloidal Fuel.** HEDRICK, J. E. *Engineer, Lond.*, 1941, **172** (21), 361–2. Describes characteristics of coal-oil mixtures and the mechanism, with performance data, of grinding coal in a ball mill. Much work needs to be done still on mixing and atomizing. [P]

1960. **Preparation of Clay Containing Coal.** HENTZSCHEL, W. *Bergbau, Forschungsheft Series A*, 1954 (22), 27–44; *Chem. Abstr.*, 1954, **48**, 11027.

1961. **Friability, Grindability, Chemical Analysis and High and Low Temperature Carbonization Assays of Alabama Coals.** HERTZOG, E. S., CUDWORTH, J. R., SELVIG, W. A. and ODE, W. H. *Tech. Pap. Bur. Min., Wash.*, No. 611, 1940. In the ball mill grindability tests, there is no replenishment between stages of grinding.

1962. **Characteristics of Pulverized Fuels.** HEYWOOD, H. *J. Inst. Fuel.*, 1933, **6**, 241. The properties of samples of pulverized coal produced by various means are discussed: Fineness characteristic curve, shape of particles, distribution of ash, petrological constituents. The general conclusion is that the intensity of air-sweeping controls the characteristics of the product to a greater extent than the type of mill, but that the characteristics of pulverized coals produced by mills in common use do not differ to any practical extent. [P]

1963. **The Resistance to Grinding of Coals.** HEYWOOD, H. *J. Inst. Fuel.*, 1935, **9**, 94. Eight coals covering a wide range of resistance to grinding and also shale pyrites and calcite were subjected to the following tests. (1) Attrition in a laboratory mill. (2) Crushing tests on cubes. (3) Impact tests on irregular pieces. (4) Crushing between rolls. (5) Scratch hardness test. (6) Resistance to abrasion. (7) Hardgrove grindability test. (8) U.S. Bureau of Mines ball mill test. Results showed that cubes required least energy per square foot of area produced, the efficiencies of impact and crushing roll tests were the same as that of compression test when the energy supplied was just sufficient to shatter the particles. Efficiency diminished when more energy was used. The resistance to grinding should be measured in such a manner that the fineness of the laboratory product is approximately the same as the fineness of the industrial product.

1964. **Review of the Literature on the Grinding of Coal. To 1937.** HEYWOOD, H. *Combustion Appliance Makers Association Document*, No. 1657, 18 Feb. 1938. 122 refs. are annotated and classified. Prefaces to the 5 main sections. A large proportion is reproduced in the present bibliography. The C.A.M.A. has been superseded by the British Coal Utilization Research Association.

1965. **Crushers Cinch Fuel Sizing.** HICKS, T. *Power*, 1951, **95**, 73–5.

1966. **Lurgi Mahltrochnungs Process (Pulvo-Drying).** HOFFMAN, H. D. *Naval Technical Mission in Europe*, 1947. O.T.S., U.S. Dept. Commerce. PB. 22497, 72 pp. A process developed jointly by Krupps and the Lurgi Gesellschaft für Wärme-Technik, for drying and disintegrating in suspension, of a high water-content coal of the lignite type. Full details are given, supported by illustrations. The process has some real merit, but appears somewhat complicated.

1967. **Crushing Coal for the Power Plant.** HUDSON, W. G. *Power Plant (Engng)*, 1947, **51**, 73–5.

1968. **The Characteristics of Pulverized Coal. The Effect of Type of Mill and Kind of Coal.** HURLEY, T. F., COOKE, R. and FITTON, A. *Tech. Pap. Fuel Res., Lond.*, No. 49, 1947. German coals were examined for fineness and structure as influenced by the method of grinding and nature of coal, Rosin and Rammler, *Zement*, **16**, 1927. Similar information is now presented for English coals. The data are presented in tabular and

graphical form, the product from six types of mill are illustrated, and conclusions are presented. 38 pp. [P]

1969. **Course and Control of Operations for Crushing Coal.** JACOBI, E. U.S. Dept. Commerce, O.T.S., PB. 73712, 1940. Obtainable in microfilm or photostat form from: Lending Library Unit, D.S.I.R. Ref. F.I.A.T. Microfilm Reel I, No. 274, Frames 5339–62. Consideration of the behaviour of various crusher constructions. *See also* No. 752.

1970. **New Information on the Influence of the Grinding and Mixing Plants used for Coking Coals on the Properties of the Coke.** JENKNER, A. *Glückauf*, 1952, **88**, 363.

1971. **Functional and Constructional Characteristics of Coal Pulverizers.** JOLLY, M., *et al. Mem. Soc. belge Ing.*, 1945, B. 245–6.

1972. **Preparation of Solid Fuels.—Coal.** JONES, W. IDRIS. *Trans. 4th World Power Conference, London*, 1950, **2**, 351–7.

1973. **Research in the Coal Industry.** JONES, W. IDRIS. *J.R. Soc. Arts*, 4 Mar. 1955, **53** (4946), 234–53, Cadman Memorial Lecture. Laboratory experiments with reference to underground cutting. A sharp edge-cutter is better. Impact wastes a lot of energy until the coal breaks, but impact uses much less energy than shear. In drilling rock with a fluted drill, at low pressure it goes in only about 1/1000 in. per revolution, but at higher pressures, up to 600 lb/sq. in., the tungsten-carbide tipped drill goes in at rates up to 16 ft/min without undue wear.

1974. **Further Developments in Beater Mills.** JUTTE, K. *Brennst.-Wärmekr.*, 1952, **4** (8), 253–8. The increasing usefulness of beater mills for pulverized coal firing and other applications is emphasized. The characteristics of construction, operation, classification, etc., are described. The improvements in energy requirements and output and other operational improvements over the last ten years are presented graphically.

1975. **Pulverized Fuel Firing in the Foundry.** KESSELS, K. von. *Stahl-u-Eisen, Düsseldorf*, 1951, **71** (2), 53–64. Tabulated data are given on the performance of various types of mill. [P]

1976. **Surface Area of Coal.** KINI, K. A., NANDI, J. N., IYENGAR, M. S. and LAHIRI, A., *Fuel, Lond.*, 1956, **35** (1), 71–6. Based on a study of the adsorption of polar and non-polar gases by British anthracite and other phenomena, as a contribution to explaining the anomaly of the surface area of coal.

1977. **Reflections on Coal Pulverizing Mills and Furnaces.** KNEUSE, H. *Mitteilungen Vereinigung Grosskesselbesitzer*, 1953 (22), 329–33. The relationship between fineness of grinding, combustion efficiency and secondary air is discussed. It is suggested that particle size has received too much attention, for tests with pulverized fuel fired boilers have shown that burning is greatly influenced by the angle between secondary and primary air and by the velocity of the former.

1978. **Determination of Grindability Coefficient of Fuels.** KOWALEV, A. P. and KAGAN, J. A. *Energie u Tech.*, June 1954, **4**, 274–6; *Fuel Abstr.*, 1955 (2), 1920.

1979. **Grindabilities of South African Duff Coals.** LA GRANGE, C. C. *J. Chem. Soc., S. Afr.*, Dec. 1946, **47**, 217–23. As determined by the A.S.T.M. ball mill method: from *Woodall Duckham Abstracts*, April 1947, 23 and 30, 310.

1980. **Tests of the Grindability of Some Fuels.** LEHMANN, H. *Energietechnik*, June 1952, **2**, 164–8. The grindability of three types of coal differing in volatile matter from 0·65% to 25·5% were investigated in an experimental tube mill, and a Loesche pulverizer. In the tube mill, all variables were kept constant and the residue on various sieves determined. In the Loesche mill, residue and power consumption were determined as a function of sifter speed. [P]

1981. **Coal Blending and Grinding for Carbonization Purposes.** LITTLECHILD, J. E.

Gas World (Coking Section), 6 June, 1953, 91–9. The author discusses the need for coal blending in modern carbonization practice. The increasing scarcity of good coking coals makes it important to crush all coals for coking finely enough for them to be mixed and blended effectively. Dispersal of the mineral matter in the coal improves the strength of the coke. Thus grinding of coal is not only both useful but necessary. In South Wales coking coal is ground to 80% passing a ½-mm aperture. The operation is in three stages: (1) coarse crushing; (2) intermediate crushing; and (3) fine crushing. The merits of jaw, toothed roll, gyratory and Bradford crushers are described. An important advantage of the Bradford crusher is that it is selective, enabling a reduction of ash content to be made during crushing. For intermediate crushing, the hammer mill, cage disintegrator and roll crusher give a product between 10 and 30 mesh. For fine grinding, the ball, tube or rod mill, the centrifugal mill or attrition grinder are suitable. 25 refs.

1982. **Thermal Expansion of Coal.** MACRAE, J. C. and RYDER, C. *Nature, Lond.*, 6 Aug. 1955, **176** (4475), 265. Describes preliminary determinations of the expansion of coal. The results serve to indicate anisotropy of the anthracite tester.

1983. **Breaking Coal with 'Airdox'.** MALESKY, J. S. *Inform. Circ. U.S. Bur. Min.*, No. 7480, 1948. Mechanical Mining by air pressure at 10 000 lb/sq. in. 9 pp., 12 figs.

1984. **New Viewpoint on Control of Coal Preparation Plants.** MEYER, G. A. H. *Glückauf*, 25 Sept. 1954, **90**, 1219–31, 1307–9; *Fuel Abstr.*, Feb. 1955, 1120, 1124. A review of the coal preparation papers at the 2nd International Congress on Coal Preparation at Essen, 1954.

1985. **Standard Methods of Coal Testing and Classification.** MINCHIN, L. T. *Gas World*, 1953, **138**, 1640–1.

1986. **Effect of Water on the Grindability of Coal.** MORIKAWA, IGURO and ABE. *J. Fuel Soc., Japan*, 1940, **19**, 125–36.

1987. **'Atritor' Pulverizer and some Typical Applications to Furnaces.** MORLAND, A. G. Proceedings Pulverized Fuel Conference, Harrogate, 1947, 212–16. Institute of Fuel. 2 gns.

1988. **Superfine Grinding of Coke and Other Materials.** MOTT, R. A. *J. Soc. Chem. Ind., Lond.*, 1950, **69** (11), 346–9. Author's Abstract. 'The methods for superfine grinding are reviewed in the light of recent experience at the Midland Coke Research Station during the grinding of coke and other materials. The wet and dry processes are compared, and it is shown that with dry grinding the end of effective grinding is caused by caking of the material in the mill. Wet grinding, by avoiding ultimate caking, enables grinding to continue to a further stage. The effect of size and type of ball is discussed and the benefits obtained by adding different alkalis and other materials during wet grinding are described and compared.' *See also under* Superfine Grinding.

1989. **The Size Reduction and Sample Division of the Moisture Sample of Coke for General Analysis.** MOTT, R. A. and TURNER, R. W. *Gas World*, 1955, **47** (510), 31–7. In the price structure of coke, moisture has been the only factor taken into account. It is now proposed to extend the scheme to include ash and sulphur content and the 1½- and ½-in. shatter indices. For 'Precision of Coke Shatter Test' *see Gas World* (Coking Section), 1953, **43**, 34.

1990. **The Preparation of Gross Samples of Coal for General Analysis: Milling, Sample Division and Mixing.** MOTT, R. A. and THOMAS, W. C. *J. Inst. Fuel*, Oct. 1956, **39** (189), 410–16.

1991. **New Methods of Preparing Coking Blends.** (In Polish.) NADZIAKIEWICZ, J. *Przegl. górn.*, 1951, **7**, 73–5.

1992. **The Shape and Specific Surface of Coal Particles.** NEEDHAM, L. W. and HILL,

N. W. *Fuel*, 1935, **14**, 222. The paper discusses a modified method of allowing for the shape of particles when calculating the specific surface, assuming that the coal particles are approximately rectangular prismatic in shape. An equation is derived, equating surface area to shape factor, density, mean projected diameter and the volume coefficient, the latter based on Martin and Bowes formula. The calculated values were found to be in good agreement with experimental determinations after coating the coal particles with plasticine.

1993. **Performance and Efficiency of Coal Preparation Plants.** NEEDHAM, L. W. Symposium on Coal Preparation, Leeds University, Dept. of Mining, 1952, 197–217; *Fuel Abstr.*, Oct. 1954, 3392. [P]

1994. **New Operating Experience with Pulverizing Low Temperature Coke in Ball Mills, for Power Stations.** NEUBERT, A. *Energie u Tech.*, Jan. 1954, **4**, 3–7; *Fuel Abstr.*, 1954, **16** (1), 210. The drum is lined with steel plates, with 4–6-cm steel balls, and with inert gas and slight pressure. Data on output—power ratio and wear costs are given. [P]

1995. **Experience with Crushing Wheel and Hammer Mills for Dirty Coal.** NOETZLIN, G. *Mitteilungen Vereinigung Grosskesselbesitzer*, April, 1954 (28), 92–102. Results with various German impact mills are given. [P]

1996. **The Indentation Hardness of Coal.** O'NEILL, H. *J. Inst. Fuel*, 1937, **10**, 351. Scratch hardness, ball and diamond cone tests are described and values for coals given.

1997. **The Coal Pulverizing Plant at McGill Smelter of the Kennecott Copper Corpn.** PESOUT, E. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 197–202; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1822, 1945, 6 pp. Two Hardinge Mills preceded by a rotary dryer are used alternately to feed the reverberatory furnace. Operating results are reported and it is stated that the power consumption per mill is 28·7 kW for an output of 8 tons per hour. Balls are added daily at the rate of 1/20 lb/ton of coal pulverized. [P]

1998. **Properties of Coal Pulverizers.** RAMMLER, E. *Ber. Reicheskohlenrates*, No. 25; *Arch. Wärmew.*, 1931, **12**, 83. Enumerates 25 requirements of an ideal grinding plant. Considers the operation and efficiency of five main types of mill.

1999. **Problems of Guaranteeing Fineness of Grinding in Coal Pulverizing Mills.** RAMMLER, E. *Energie u Tech.*, Aug. 1952, **2**, 232–6. A specified maximum to be retained on a particular sieve generally involves a residue on a larger mesh sieve, the larger particles entailing a disproportionate loss in combustible value. The coarser material becomes greater as 'n' in the distribution curve becomes greater, and the variations are discussed in detail and presented in tabular and graphic form.

2000. **Fineness Classification of Ground Material.** RAMMLER, E. and GLOCKNER, E. *Bergbau, Forschungsheft*, Series A, 1953 (15), 5–21; *Chem. Abstr.*, 1954, **48**, 7875; *Fuel Abstr.*, Dec. 1954, 5379. A study of the laws governing the distribution particle size of ground coal.

2001. **Considerations Affecting Selection of Pulverizers.** REID, S. H. *Combustion, N.Y.*, 1938 (10), 26–8. The effect of coal characteristics and required fineness on mill capacity is discussed as well as drying and tempering in the mill. Recommended fineness for high- and low-volatile coals is given and the influence of operating conditions on the number of mills selected is considered. 7 graphs.

2002. **Coal Preparation.** RICHARDSON, A. C. *Min. Congr. J., Wash.*, 1947, **33**, 42–3.

2003. **Quality Preparation Assured in Markson Breaker Design.** RICHART, R. R. *Coal Age*, 1947, **52** (11), 82–7.

2004. **Characteristics of Coal Pulverizers.** ROSIN, P. *Arch. Wärmew.*, 1925, **6** (11),

289–94. The mathematical relationship between the controlling factors is investigated with a view to predicting operational power requirements. Power requirements for idle and operational motion are evaluated, and tabulated for various types of mill. The relationships are summarized by Heywood in *Combustion Appliance Makers' Association Document*, No. 1657, 1938, p. 71.

2005. **Power Consumption of Coal Pulverizers. I.** ROSIN, P. and RAMMLER, E. *Ber. Reichskohlenrates*, No. 3; *Arch. Wärmew.*, 1926, **7**, 54, 81. An extension of the previous work on the characteristics of coal pulverizers by Rosin. It concerns mathematical relations between: (1) output and energy at constant grindability and fineness; (2) grindability and energy at a constant fineness and output; and (3) fineness and energy at constant output and grindability. [P]

2006. **Power Consumption of Coal Pulverizers. III.** ROSIN, P. and RAMMLER, E. *Ber. Reichskohlenrates*, No. 12; *Arch. Wärmew*, 1927, **8**, 239–43. A translation may be consulted at D.S.I.R. Ref., Records Section, 12207. The relationship between power requirements, output and fineness for different conditions of operation of a Fuller Lehigh mill with a sieve classifier. [P]

2007. **Mill Drying.** ROSIN, P. and RAMMLER, E. *Ber. Reichskohlenrates*, No. 10; *Braunkohle*, 1927, **27**, 261, 286. Ring roll mill performance on coal with simultaneous drying and grinding. Heat requirements and the necessary compromise between grinding and drying requirements are dealt with. [P]

2008. **Fineness and Structure of Powdered Coal as Influenced by the Method of Grinding and Nature of Coal.** ROSIN, P. and RAMMLER, E. *Z. Ver. dtsch. Ing.*, 1927, **71**, 1; *Zement*, 1927, **16**, 820, 840, 871, 897. A wide range of coals were ground in many types of mill. Sieving curves and microphotographs of particles are given for each test. It is concluded that fineness distribution and particle shape are independent of the type of mill. [P]

2009. **Suggestions for Pulverizer Experiments.** ROSIN, P. and RAMMLER, E. *Ber. Reichskohlenrates*, No. 16; *Zement*, 1929, **18**, 632; *Braunkohle*, 1929, **28**, 221. A detailed description is given of the procedure for testing pulverizers. A translation has been published in *Combustion Appliance Makers' Association Document*, No. 1380, 1929, under the heading 'Testing of Pulverized Fuel Installations for Commercial and Scientific Purposes'. C.A.M.A. is now superseded by the British Coal Utilization Research Association, Leatherhead, Surrey.

2010. **Grinding Coke.** ROSIN, P. and RAMMLER, E. *Ber. Reichskohlenrates*, No. 25; *Braunkohle*, 1930, **29**, 477, 497. Grindability factors for coke, spontaneous combustion and the tendency to explosion, required fineness of grinding and suitable mills are discussed. Results of experiments with Loesche mill, sieveless tube mills, airswept mills and Fuller Lehigh mills are presented. [P]

2011. **Grindability of Coal.** ROSIN, P. and RAMMLER, E. *Ber. Reichskohlenrates*, No. 25; *Zement*, 1931, **20**, 210, 240, 317, 343, 365. Performance of several mills on several coals, and effects of coal characteristics, i.e. strength, ash content, moisture, particle size and grindability are dealt with. Grinding experiments with a sieveless three-chamber tube mill grinding three types of coal are described. Comparative experiments with five types of coal ground in a simple tube mill and a ring roll mill were carried out and the conditions inside the mills investigated, e.g. regarding gradation of sizes. [P]

2012. **The Grinding of Coal in a Ring-Ball Mill.** FUEL RESEARCH BOARD B.C.U.R.A. JOINT CTTEE. *J. Inst. Fuel*, 1957, **30** (196), 269–275. The conclusions after a two year investigation are discussed in thirteen paragraphs.

2013. **The Laws Governing the Fineness of Powdered Coal.** ROSIN, P. and RAMMLER, E. *J. Inst. Fuel*, 1933, **7**, 29–36. The first publication in English on this subject. *See under* Size Distribution.

2014. **Particle Size Problems of Pulverized Coal and their Significance in Grinding.** Rosin, P., Rammler, E. and Sperling, K. *Ber. Reichskohlenrates*, No. C.52; *Wärme*, 1933, **56**, 783. Deduction of the exponential law of size-distribution from probability considerations and grinding experiments. Determination of size constants and conditions defining the distribution maximum. Application to tube mills.

2015. **The Influence of Particle Size in Processes of Fuel Technology.** Rosin, P. *J. Inst. Fuel*, 1937, **11**, 26. Influence of above on ignition, conduction, flow of gases through beds, motion in fluids of coal particles. [P]

2016. **Power Consumption of Coal Pulverizers. II.** Rosin, P. and Schulz, E. *Ber. Reichskohlenrates*, No. 9; *Arch. Wärmew.*, 1927, **8**, 69–73, 109–15. A translation may be consulted at D.S.I.R. Ref., Records Section, 12199. Discusses 'empty' power, the effect of moisture content on the relationship between output and energy, the influence of the air classifier and the effect of fineness on the energy and output. [P]

2017. **Present Position of Brown Coal Preparation.** Schlager, A. *Montan. Rdsch.*, Mar. 1954, **2**, 37–40; *Fuel Abstr.*, Sept. 1954, 2464.

2018. **Sampling Devices Help Check Coal Mill Performance.** Schuder, C. B. *Power*, Jan. 1954, **98**, 94. Regular tests are recommended depending on mill wear. Fifteen items are suggested for observation and record, to include mill characteristics, coal moisture and other data, and fly ash data. Presents three sampling devices for sealing into the pulverized fuel tubes. [P]

2019. **Development of Pulverized-coal Mills.** Schulte, F. *Wärme*, 1939, **62**, 772. An illustrated historical and critical survey of the recent development of the different types of coal-dust mills, e.g. tube or gravity mills, roller mills of the Raymond, Fuller and Loesche design, beater mills and baffle-plate mills. By the introduction of hot-air drying of the material during milling, the use of wind sifters and the direct feeding of the coal dust from the mill into the burners, the mills have been adapted more and more to modern requirements. The beater mill has its special field of application in the combined mill firing system of the Kramer type.

2020. **Grindability of Bituminous Coals.** Schultes, W. and Goecke, E. *Arch. Wärmew.*, 1932, **13**, 253. Effects of air sweeping, mill loading and volatile matter are ascertained from experiments on a range of coals.

2021. **The H.S. Mill. Construction, Application, Performance.** Seidl, H. *Arch. Wärmew.*, April 1942, **23**, 81–5. Comparison of performance data from this hammer mill with that of the Kramer mill for various brown coals and hard coals. The H.S. mill is a development of the Kramer mill and is suitable for pulverizing and drying all but the hardest coals, whereas the Kramer mill was not. The comparisons show the superiority of the H.S. mill. [P]

2022. **Pulverization of Coal with Steam.** Seleznер, V. V. *Energetik (Power Engineering, Moscow)*, Mar. 1955, **10**, 12; *Fuel Abstr.*, Aug. 1955, 1528. A description is given of apparatus used for existing hand-fired boilers giving 8–10 tons of steam per hour. The fuel is pulverized against a horizontal plate in a jet of superheated steam at 80–100 metres per second velocity. Oversize is returned before passing to the burners.

2023. **A Study of Adsorption as a Method for the Determination of the Surface of Pulverized Coal.** Sherman, R. A., Irion, C. E. and Rogers, E. J. *Proc. Amer. Soc. Test. Mater.*, 1933, **33** (2), 729. Tests showed that adsorption of methylene blue on sieved fractions of various coals was not directly proportional to surface, nor was it the same for different coals. The authors conclude that this method has no value for grindability measurements.

2024. **Crushing Action of Stoker Feed Screws.** Shotts, R. Q. Alabama State Mines Experimental Station; School of Mines University of Alabama; Contribution No. 1, *Coal Heat*, 16, 20, 21 Sept. 1947.

2025. **Experiences with U.S. Coals in Gas and Coke Production in Kiel Gas Works.** SIEBEL, H. *Gas- u. Wasserfach*, 1952, **93**, 15–19.

2026. **Balancing (Mechanical) of Coal Mills.** SIEBERT, O. *Mitteilungen Vereinigung Grosskesselbesitzer*, July 1954 (29), 150–9.

2027. **Determination of the Specific Strength of Coal.** SIMEK, B. G., PULKRABEK, J. and COUFALIK, J. *Mitt. KohlenforschInst. Prag.*, 1935, **2**, 194, 237. Results of sand-blasting tests on small sections of coal are reported with photographs.

2028. **Modern Pulverized Fuel Steam Raising Plant.** SMEATON, J. *Iron Coal Tr. Rev.*, 19 Dec. 1947, **155**, 1206–10. The development and present design of coal pulverizers and large pulverized fuel boilers are outlined. Mill types, etc., are described.

2029. **Friability of Different Coals.** SMITH, C. M. *Illinois Engineering Experimental Station Report*, No. 196, 1929. Lumps 2 × 3 in. are dropped 10 ft on to a concrete floor and the product sieved. The results are expressed by a degradation number expressed as the weight of pieces compared with the original, rather than a size relationship; e.g. if pieces are half the original weight, the degradation number is 50%. A table of results is given. *See* their *Bull.* 218, The Friability of Illinois Coals.

2030. **Pulverizer Performance.** SMITH, V. *Elect. Rev., Lond.*, 1948, **143**, 553–5. Comparison of three types of mill for grinding coal. Effects of moisture content beginning at 5%. Maintenance costs. Power consumption and efficiency. [P]

2031. **Notes on the Selection of Pulverizers.** SMITH, V. *Cheap Steam*, Sept. 1950, **34**, 107–9. The effects on the performance of pulverized fuel of the various governing factors are discussed, including those of degree of fineness, grindability and quantities required. [P]

2032. **The Significance of the Hammermill in the Coal Industry.** (In German.) SPIES, H. *Geol. en Mijnb.*, 1954, **16**, 389–97. After a discussion of the theory and mode of action of the hammer mill, the results of extensive investigations on the breakage of various coals are presented in a series of tables. [P]

2033. **Method for Feeding Fuel.** STEPHANOFF, N. N., WHEELER MANUFACTURING CO. *U.S. Pat.* 2550390, 1944. Ground fuel receives a preliminary pulverization by the impact of high-pressure steam jets or other gases. The suspension passes tangentially round a circular vessel where oversize is separated and returned to the closed pulverizing circuit. The smaller particles pass through venturi arranged in a ring around the axis of the vessel. The sudden pressure drop disintegrates the porous fuel while the unwanted mineral particles can be separated in a cyclone, leaving the fuel to be conveyed to the burners. The preliminary pulverizer is adapted for pulverizing the size of pea coal, which is fed from a crusher into a large endless tube to meet steam or fluid jets entering at the lower part. The venturi are set in the circular wall of the upper part of the structure.

2034. **Grindability of Coal.** TACHIKAWA, S. and IKAI, S. *J. Fuel Soc. Japan*, July/Aug. 1950, **29**, 156–61; *Fuel Abstr.*, July 1954, 165. Using a ball mill pulverizer, the relations between various constants, conditions of pulverizing, kind of coal and degree of coalification were studied experimentally. The accuracy of Rosin and Rammler's equation for the grindability of coal was determined for Japanese coals.

2035. **Coal Crushers.** TAYLOR, E. *Brit. Pat.* 576326, 1944. To increase capacity without increasing the dimensions of the equipment, the coal is first crushed between a roller and a stationary member, then between the two rollers (of different sizes); the product is then divided and fed between the rollers and spring tensioned crushing members.

2036. **Improvements Relating to Coal Crushers.** TAYLOR, E. *Brit. Pat.* 724477, 1955. The crusher is designed to crush large lumps between a toothed roll and a breaker plate from which the smaller lumps fall down between the first roll and a second,

smaller roll, the resulting product then falling on to a dividing ridge to be crushed again between the individual rolls and nearly horizontal breaker plates.

2037. **The Fine Crushing of Coal and Coke.** TAYLOR, J. *J. Inst. Fuel,* May 1954, **27** (160), 249–54. *See under* Theory Size Distribution.

2038. **The Breakage of Coke by Mechanical Means.** TAYLOR, V. T. and HEBDEN, D. *Commun. Gas Res. Bd.,* No. 42, 1948. An interim report on the study of cleavage and crushing. As a first step the influence of eight variables on the production of breeze has been investigated using a two-roll breaker. Sampling for size analysis and mechanical methods of size analysis are discussed in appendices. 54 pp.

2039. **Process for Disintegrating Solid Materials.** TEXACO DEVELOPMENT CO., EASTMAN, D., GAUCHER, L. P. and CARKEEK, C. R. *Brit. Pat.* 683318, 1951. A slurry of crushed coal is passed at high pressure through a heater in turbulent flow, where the water is vaporized and the fine particles are dispersed in the steam. The velocity of the latter should be at least 60 ft/s (up to 500 ft/s) and sufficient to shatter the particles by collision. The mixture of fine solid and steam is passed with oxygen into a synthesis gas generator to form carbon monoxide and hydrogen. Venturi or baffles at the outlet for sudden change of pressure or velocity assist the disintegration.

2040. **Operational Experiences with Pulverizer Stokers for Raw Brown Coal.** TOLLE, H. *Energietechnik.,* April, 1954, **4**, 161–8; *Fuel Abstr.,* 1954, **9**, 2753.

2041. **Effect of Grinding Coal on the Quality of the Coke.** (In Russian.) TSIPEROVICH, M. V. *Stal,* 1948, **8**, 967–73.

2042. **Some Fundamental Principles Applied to the Design and Operation of a Fine Anthracite Plant at Coaldale Colliery.** TURRALL, W. T. and COOK, M. J. *Min. Engng, N.Y.,* **5**; *Trans. Amer. Inst. min. (metall.) Engrs,* 1953, **196**, 910–21. Illustrations, flowsheet, tables, bibliography.

2043. **Coal Preparation. A Mineral Engineering Problem.** TURRALL, W. T. *Canad. Min. metall. Bull.,* Dec. 1954, **47**, 822–4; *Fuel Abstr.,* May 1955, 4109. A review of coal preparation engineering.

2044. **Some Thoughts on Coal Pulverization.** VERNON. P. V. *Engineer, Lond.,* 1928, **145**, 176. Includes performance data for high-speed impact mill. 40 h.p. for 2 tons per hour, but deducting power for fan the horsepower available for pulverization was 11·5 h.p./ton. [P]

2045. **The Friability of South African Coal.** VOGEL, J. C. and QUASS, F. W. *J. Chem. Soc. S. Afr.,* 1937, **37** (8); *Bull. Fuel Res. Inst. S. Afr.,* No. 9, 1937, 10 pp. The degradation products of shatter tests on twenty-five South African coals are shown to conform to Rosin's law of size distribution. The Rosin constants (absolute size constant and size distribution constant) have been suggested for evaluation of degradation test results in place of percentage friability, the former as a measure of resistance to breakage and the latter as a measure of dust-forming tendency. The advantages are indicated. The concentration of mineral matter in the various sizes of broken coal is discussed.

2046. **Coal Pulverizing and Blending Plants.** WEHRMANN, F. *Gas- u. Wasserfach,* 1 Feb. 1955, **96**, 75–8; *Fuel Abstr.,* Aug. 1955, 1138. The various types of equipment which can be used at gas works are considered.

2047. **Coal Preparation. Some Developments related to Pulverized Fuel Practice.** WILKINS, E. T. Proceedings Pulverized Fuel Conference, Harrogate, 1947, 398–407. Institute of Fuel. 2 gns.

2048. **Direct Pulverized Fuel Firing of Shell Type Boilers.** WILSON, R. Proceedings Pulverized Fuel Conference, Harrogate, 1947. Institute of Fuel. 2 gns. A 5·3% ash coal gave 10% lower cost of equipment and 36% greater output/kWh than a 16·2%

ash coal. *Air-swept ball mills* require higher power consumption than ring mill and high-speed impact pulverizers. Dependability is greater, maintenance lower, and simpler, and are efficient for coals up to 10% moisture. Capacity depends on (1) grindability, (2) fineness of product, (3) moisture content of coal, (4) temperature of air. (300°–350°F is suitable for moisture content of 7%.) [P]

2049. **Present Methods of Coal Pulverization in Belgian Power Plants.** WILWERTZ, C. *Trns. 4th World Power Conference, London,* 1950, **2**, 462–9.

2050. **A Small Laboratory Pulverizer. (For Coal.)** WRIGHT, B. M. *Chem. & Ind. (Rev.),* 3 Jan. 1953, **26**, 8–10. *See under* Hammer Mills.

2051. **Comparison of Methods for Determining the Friability of Coal.** YANCEY, H. F. and ZANE, R. E. *Rep. Invest. U.S. Bur. Min.,* No. 3215, 1933. Tumbling and shatter tests are described. A coal which is susceptible to degradation by shatter or impact is not necessarily susceptible to breakage by abrasion or attrition. The drop test simulates handling in chutes, but tumbling is better for measuring degradation in mass transport.

2052. **Estimation of the Grindability of Coal.** YANCEY, H. F., FURSE, O. L. and BLACKBURN, R. A. *Trans. Amer. Inst. min. (metall.) Engrs,* 1934, **108**, 267. A summary with full details of tests is given in *Combustion Appliance Makers' Association Document,* No. 1657, 1938, pp. 57–62.

2053. **Ball Mill Grindability Indexes of Some American Coals.** YANCEY, H. F. and GEER, M. R. *Rep. Invest. U.S. Bur. Min.,* No. 3409, 1938, 9 pp. The U.S. Standard ball mill method was used for 34 samples of coals by the N.W. Experimental Station of the Bureau of Mines in co-operation with the College of Mines at the University of Washington. It was found that in general, increasing fixed carbon accompanied increasing grindability, i.e. low-volatile coals are decidedly easier to grind than the high-volatile class. But anthracite and sub-bituminous coals are more difficult to grind. A table is presented comparing the ball mill grindability index with the equivalent Hardgrove grindability index.

2054. **An Investigation of the Abrasiveness of Coal and its Associated Impurities.** YANCEY, H. F., GEER, M. R. and PRICE, J. D. *Min. Engng, N.Y.,* 3; *Trans. Amer. Inst. min. (metall.) Engrs,* 1951, **190**, 262–8. A laboratory procedure for estimating the abrasiveness of coal is developed, in which the amount of wear on the blades is taken as a measure of abrasiveness. Test results are reasonably precise. The impurities are more abrasive than the coal substance (up to 30 times as abrasive). A test procedure is described.

2055. **Coal Atomizer.** YELLOTT, J. I. and SINGH, A. D. *Pwr Plant (Engng),* 1945, **49** (12), 82–6. This method is based on the explosion principle used for 'puffed' cereals, except that it is a continuous method. Crushed coal is stored in a hopper under pressure and is fed by a screw into a pipe containing superheated steam. The steam forces the coal along through a gradual constriction in the pipe, and the rapid changes in pressure force steam into the coal and shatter it when the pressure drops on the other side of the nozzle. A bituminous coal, $-16+30$ mesh, was tried; only about 5% was left of this size, the peaks being at 60 mesh and -270 mesh. The higher the initial pressure, the more shattering occurred; steam temperature had little effect. With 0·725 lb of steam per pound of coal a maximum surface is reached, which is not increased by more steam. Recycling increases the finest fraction. The coal is dried by the process; a lignite dropped from 37% moisture in the feed to 4%. There are no moving parts except the feeding screw. Bituminous coal has little wearing effect on the steel nozzle; coke, however, will wear it, and a boron carbide nozzle is recommended. The product is caught in a cyclone. Air can be substituted for steam. 6 refs., 8 figs. Joint investigation by the Institute of Gas Technology, Chicago, and the Locomotive Development Committee of Bituminous Research Inc.

2056. **Mechanical Crushing of Bituminous Coal and Methods for Allaying Dust.**

YOUNG, W. A. and ANDERSON, R. L. *Mechanization*, 1951, **15**, 163, 165, 167; 1952, **16**, 95, 96. Includes data on lignite.

ENAMEL

2057. **Grinding of Enamel and Supervision of Particle Size in Enamel Slips.** ANON. *Glashütte*, 1942, **72**, 157, 247, Abstract in *J. Soc. Glass Tech.*, 1948, **32**, 183.

2058. **Relation of Milling Practice to Enamel Workability.** BAKER, R. J. and SHELDON, R. S. *Proc. Porcel. Enam. Inst.*, 1953, **15**, 66–74. *See under* Ball Milling, *and under* Ball Media, Vernetti.

2059. **Enamel Milling.** BENNETT, R. W. H. *Foundry Tr. J.*, 3 June 1954, **96** (1970), 639. The paper deals with the requirements of pebble mills generally, then with the characteristics of enamel milling and the use of rubber-lined mills. Factors promoting mill efficiency, pebble size and grading, frit loading and water content. Mill linings of orthodox type are compared with a rubber mill produced by the author's firm, the Linatex ball mill. This consists of a shell built up from rubber rings and tie rods, and can be mounted in the ordinary way. Data on mill speeds, diameter, charge, are presented graphically and a loading table included. A very long life is expected from rubber mills and freedom from contamination of product.

2060. **The Milling of Porcelain Enamels.** BIDDULPH, A. *Enamelist*, 1945, **22** (15), 7. Previous work on the theory of ball milling is briefly reviewed. Most of the grinding of enamels takes places by attrition rather than impact, and the angle of nip is therefore an important factor. Milling efficiency is affected by the pebble charge and size, the frit charge, water content, temperature and speed of revolution. The pebbles should occupy 55% by volume of the mill. The correct size is indicated in the following table:

Mill Diameter	Pebble Size
1 ft	80% at 1 in.; 20% at 2 in.
2 ft	80% at 1½ in.; 20% at 2 in.
3 ft	75% at 1½ in.; 25% at 2½ in.
4 ft	40% at 1½ in.; 40% at 2 in. 20% at 2½ in.

Using a steel ground-coat frit, experiments indicated that the optimum water content for milling was about 55%; this figure is considerably higher than a previously reported optimum, and may be due to a difference in the 'set' of the enamel. Experience suggests the following range of mill speeds for efficient working:

Mill Diameter	Speed (rev/min)
1 ft	68
2 ft	48
3 ft	37
4 ft	30
5 ft	24
6 ft	21

Notes are added on mill-room layout and equipment, operational practice and testing methods.

2061. **Milling of Enamels.** BIDDULPH, A. *Found. Trade J.*, 1945, **75**, 343. A review of published information and a description of the best conditions for grinding in the ball mill. Discussion.

2062. **Milling of Enamels.** BIDDULPH, A. *Found. Tr. J.*, 1946, **78**, 265. A discussion is given on the milling of enamels including the milling theory, the angle of nip, pebble size, water content, temperatures, mill cleanliness, mill-room layout, mill equipment, storing of frit, milling practice, testing, dip weight, viscosity, storing and ageing, agitation and the utilization of dry enamel reclaim.

2063. **Mixing, Smelting, Grinding of Enamels.** BURT, F. M. *Ceramic Ind.*, 1926, **7**, 40, 143, 254.

2064. **Ball Milling of Glazes—Various Grinding Media.** DAVIS, H. E. *Bull. Amer. ceram. Soc.*, 1955, **32** (6), 209–10. Experiments were undertaken to determine the influence of the density and shape of the new high-density spherical and cylindrical grinding media on the wet milling of water-quenched frit. Two aspects were considered—the amount of original size remaining and the amount of product passing a 100-mesh sieve. It appears that weight is effective in original breaking down, but size of ball is chiefly effective in further reduction. Further investigation is required, especially on the loss in weight of the expensive media. Graph, refs. *See also Bulletin of the Institute of Vitreous Enamellers*, Jan. 1955, **5** (3), 83–6. [P]

2065. **Mill Room Modernization.** DUVALL, W. *Bett. Enamel.*, 1946, **17** (6), 6–10. The author elaborates on the location and function of various equipment items shown in his schematic drawing of an idealized enamel mill room. 1 fig.

2066. **A Study of the Sub-sieve Particle Size Distribution of Milled Enamels.** SAMMARONE, D. G. and SAUNDERS, H. S. *Bull. Amer. Ceram. Soc.* Sept., 1957, 340–5. A comparison is made between the Palo-Travis long tube method and a modified hydrometer method, and correlation is established.

2067. **Mill Room Variations that Affect Grinding Efficiencies.** FELLOWS, R. L. *Bett. Enamel.*, 1938, **9** (10); 1939, **10** (9); *Ceramic Abstr.*, 1940, **19**, 210. The author discusses factors affecting grinding efficiency of ball mills used in grinding porcelain enamel.

2068. **Study of Milling and its Effects on Properties of Porcelain Enamel Slips.** FELLOWS, R. L. and MCLAUGHLIN, J. L. *J. Amer. ceram. Soc.*, 1939, **22**, 260. Variations in the amount of frit charge, amount of ball charge, size of balls, and rev/min of the mill were found to change the fineness distribution of a white steel enamel. Other variables, such as the water content, temperature of milling, and pressure under which the enamel was ground, had apparently little effect on the fineness of the enamel. An increase in grinding temperature decreased the $Na_2O:B_2O_2$ ratio of the mill liquor and decreased the set of the enamel. Variation in milling under the conditions stated had no effect on the opacity or gloss and texture of the enamels. *See also Bett. Enamel.*, 1938, **9** (10), 1939, **10** (9).

2069. **Grinding Dry Process Enamel and its Effect on Working Properties.** MANSON, M. E. *J. Amer. ceram. Soc.*, 1938, **21**, 316–19. In view of the amount of powder clinging to the balls, cover and mill wall, and of other characteristics of the finely-powdered frit, series of grindings in a ball mill were made: (1) dry; (2) with the addition of small quantities of water (from 20 to 30 c.c. of water per 100 lb of frit). The water was found to be beneficial to the several characteristics tested.

2070. **Recent Advances in Grinding; Control of Particle Size in Glaze Slips.** PARMELEE, C. W. *Ceramic Ind.*, 1940, **35** (1), 48. Greatest grinding efficiency is obtained when the volume of balls used is 55% of the volume of the mill. The weight of frit charge in pounds is usually about three times the mill volume in gallons. The effect of grain-size distribution on glaze properties, and methods of controlling slip consistency are discussed. It is shown how research work on enamels may be applied also to glazes.

2071. **The Use of Finely Milled Enamel Slip.** PORTER, F. R. and HOLSCHER, H. H. *J. Amer. ceram. Soc.*, 1935, **18**, 39. Cover-coat slips for sheet iron are usually ground to 4–9% residue on a 200-mesh sieve, finer grinding being thought to cause tearing. However, slips ground to give 12–0·2% residue on a 325-mesh are now being fired successfully in practice in continuous furnaces. The advantages are: higher opacity; less wear on spray guns; smoother finishes; preferred by sprayers; better suspension; and lower firing temperatures.

2072. **The Fineness Distribution of Vitreous Enamel as Affected by Variations in Grinding.** Poste, E. P. *J. Amer. ceram. Soc.*, 1935, **18**, 303. The results of an experimental study of the effects of variations in some of the conditions of grinding vitreous enamels on the distribution of particle size are reported. Observations on the distribution of particle size in commercial batches of various enamels follow.

2073. **Milling and Mill Additions.** Spencer-Strong, G. H. *Proc. Porcel. Enam. Inst.*, 1945, 34–5, presents a rather complete procedure for milling enamels and includes the types of mill additions. For satisfactory results in porcelain-enamelling, milling is of first importance. Secondly, the mill additions must be closely controlled. Major factors influencing the efficiency of milling are (1) design of the mill, (2) speed of rotation, (3) grinding media, (4) mill charge, and (5) set of the enamel. Mill additions are generally classified as (1) suspending agents, (2) refractories, (3) electrolytes, and (4) opacifying or colouring agents. 4 refs.

2074. **Enamel Mill Room Practice.** Steele, G. *Found. Tr. J.*, 7 May 1936, **54**, 369. Conditions of charging and running ball mills to obtain maximum efficiency are discussed. Rubber-lined mills are said to be still in the experimental stage and to be limited to wet grinding.

2075. **High Density Grinding Media.** Vernetti, J. B. *Ceramic Ind.*, 1954, **62** (3), 70. Enamel frit grinding. *See* Nos.1273–4. [P]

2076. **The Influence of Temperature on the Grinding of Enamel.** Vielhaber, L. *Glas-Emael-Keramo-Technik*, 1951, **2** (39), 2087. If the enamel becomes too hot during grinding enamel faults may follow, e.g. during drying the parts exposed to the air draught dry more quickly and act as a sponge for accumulating salts, which give rise to streaks of bubbles during firing. It is possible that alkalis in the mill water combine with CO_2 from the air to form carbonates which then decompose again during firing and develop gases. However, it is suggested that mills should be water-cooled as is now normal in the U.S.A.

FELDSPAR

2077. **Feldspar Mining Plant in N. Carolina.** Anon. *Engng Min. J.*, 1943, **144**, 73.

2078. **Influence of Atmospheric Humidity on the Grinding and Screening of Solids.** (In German.) Albinsson, A. *Ark. Kemi.*, 1953, **6** (4), 293–304. Tests for determining the best particle size of feldspar for rapid melting with sand, soda and lime are described. 8 figs., 6 refs.

2079. **Milling Feldspar at Spruce Pine.** Burgess, B. C. *Ceramic Age*, 1931, **18**, 155. Information provided by the U.S. Bureau of Mines gives the latest practice in methods of preparing feldspar, unit cost factors, and other data.

2080. **Feldspar.** Lomas, L. *Mine & Quarry Engng*, 1951, **17**, 240–1, 363. The uses of feldspar are discussed. The methods of grinding and requirements for the various applications are described briefly. Discussion of fine grinding of felspar in a typical mill comprising three silex-lined mills with flint pebbles running at 27–28 rev/min. It is claimed that the plant capacity is increased by 8% when a tube mill is employed in the first stage.

FERTILIZERS

2081. **Factors Affecting Granulation in Fertilizer Mixtures.** Hardesty, J. O. and Ross, W. H. *Industr. Engng Chem. (Industr.)*, 1938, **30**, 668–72.

2082. **Calcium Cyanamide.** Kastens, M. L. and McBurney, W. G. *Industr. Engng Chem. (Industr.)*, 1951, **43** (5), 1020–33. Two-stage crushing of calcium carbide in jaw-mill and cone crusher, followed by blending with calcium cyanide and fluorspar in a ball mill to give a mixture passing 100 mesh is the method used in the early stages of

the manufacture of calcium cyanamide. The mill is divided into chambers having progressively smaller balls. The operation is carried out in a dry atmosphere.

2083. **Triple Superphosphate.** PORTER, J. J. and FRISKEN, J. *Chem. Age, Lond.*, 1952, **132** (3426), 249–50. Phosphate rock at Fison's Immingham Plant is ground by 4 Lopulco air-swept roller mills each rated to grind 12 tons per hour to a fineness of 80% through a 100-mesh sieve.

FOODSTUFFS

2084. **Size Reduction.** ANON. *Food Engng, N.Y.*, 1953, **25** (10), 157–64. A general account of the application of disintegrators in the food industry, showing how reduction technique has developed since 1920. A brief description of the appropriate mills and their operation and application to various foodstuffs.

2085. **New Laboratory Method for Drying Wheat Gluten.** ADAMS, G. A. *Cereal Chem.*, 4 July 1952, **29**, 312–4. Describes *inter alia* how deeply frozen wet gluten with liquid nitrogen or dry ice, becomes friable and is easily milled to granular form.

2086. **Fine Grinding of Brittle Organic Natural Products such as Roasted Coffee.** KIRSCHBAUM, E. and SCHMIDT, H. *Chem.-Ing.-Tech.*, 1953, **25**, 598–600. Experiments have been made to grind coffee so fine in a three-roll mill or a ball mill that it can be consumed as a cloudy beverage on stirring with water. A ball mill was not satisfactory with coffee owing to moisture content inducing packing on the walls. The paint mill, however, with a roll speed relation of 1 to 10 gave a product of 15–10 microns in a few passages through the mill, which could be water-cooled and air-enclosed to prevent loss of aroma. Results are presented in tabular form. 4 refs. [P]

2087. **Pectin. Evidence of Molecular Constitution from Dry Grinding.** LAMPITT, L. H., MONEY, R. W. and JUDGE, B. E. *Chem. Ind.* (*Rev.*), 4 Sept. 1954, 1113. An extension of previous work is described. The period of grinding of pectin in a ball mill (dry grinding) has been extended to 8000 hours. The changes in properties are described and the evidence for molecular break down is presented. 3 refs. *See J. Soc. Chem. Ind., Lond.*, 1947, **66**, 157.

GYPSUM

2088. **Burning and Grinding Gypsum in One Apparatus.** *Rock. Prod.*, 13 Aug. 1932, **35**, 46–7. Diagrams are given of three sets of equipment for the above and abstracts from *TonindustrZtg*, 1932, **56** (7), 93–6, (16), 224–7; (21), 293–4.

2089. **The Simultaneous Grinding and Drying of Clay.** GOVOROFF, A. *Rev. Matér. Constr., Edition B., L'Industrie Céramique*, 1951 (425), 223. A summary of the reports of the application in Germany of grinding gypsum in a hammer mill and drying in a current of air.

METAL POWDERS

2090. **Metal Powders: Dust Hazards.** *See under* Dust Hazards, ANON., HARTMANN, KAPELMAN and MASON.

2091. **Sintered Iron and Steel Components.** *B.I.O.S. Final Report*, No. 595, H.M. Stationery Office. Brief notes on crushing.

2092. **Iron Powder.** *B.I.O.S. Final Report*, No. 860. H.M. Stationery Office. Brief description of producing powdered iron. Five methods. Diagram of nozzle for producing powder by passing molten metal through a conical jet of water.

2093. **German Powder Metallurgy.** *F.I.A.T. Final Report*, No. 772. H.M. Stationery Office. Disintegration of hard alloys is done by blowing in the molten state with water, air or steam jets with and without rotary impacting disintegrating wheels. Drawings.

2094. **Microniser Process.** ALUMINIUM CO. OF CANADA. *Canadian Chemistry and Process Industries*, 1949, 33 (6), 483. A method of ultrafine grinding to less than 5 microns.

2095. **Modern Plant Makes Magnesium Powder.** *Chem. Engng*, 1954, **61** (4), 122–4. Description of the plant of the Reade Manufacturing Co., Lakehurst, N.J. (1) 90 day aged ingots are cut into ribbon 'chips'. (2) "Chips" are disintegrated by air blast. (3) Suitable hammer mills pulverize to 100–200-mesh product as desired, the thickness of the chips controlling the final size. (4) Sieving on gyrating sieves for close sizing. Safety features: (a) dispersed buildings; (b) good housekeeping and avoidance of dust pockets; (c) earthing all equipment; (d) magnetic separation of iron impurities (air conveyance throughout, not inert gas).

2096. **The Manufacture of Aluminium Powders.** *Sci. Mus. bibliogr. Ser.*, No. 430, 1938. 19 refs.

2097. **The Significance of Grain Size and Form in Powder Metallurgy.** BENEZOWSKY — (Reutte/Tyrol). *TonindustrZtg*, 1954, **78** (13/14), 214; Tagung Verein deutsche Ingenieure, Staubtechnik, Bad Kissingen, 1954. The methods and results in powder metallurgy depend very closely on the size and shape of the particles. These depend in turn on the methods of powder formation, the sizes lying between 0·1 and 300 mu or even 500 mu (iron powder for machine parts being about 150 mu), the shapes of powders varying from spherical to leaf form, e.g. iron carbonyl and electrolytic iron powder respectively. Specific surface, determined by the air permeability method, gives a quantitative indication of the grain shape. Evolution of size distribution by sieving, elutriation or sedimentation is evaluated by the Rosin–Rammler formula. The unsuitability or otherwise of sieve fractions or extreme sizes in pressing and sintering is described with regard to the resulting properties of the finished product.

2098. **The Rosin–Rammler Size Distribution of Ground Powders.** BRENNER, R. and VIDMAJER, A. *Metall*, 1955, **9** (9/10), 395–403. The application to powder metallurgy is discussed, and the phenomena analysed mathematically and graphically. *See* Nos. 353–4.

2099. **Determination of the Effect of Particle Size on the Properties of Commercial Iron Powders and Compacts made from these Powders by Conventional Gold Pressing and Sintering Techniques.** COMSTOCK, G. J. and SHAW, J. D., *et al.* U.S. Dept. Commerce, Office of Technical Services, Stevens Institute of Technology, July 1948. Chap. II (2): Particle size distribution. Procedure and graphed results. II (12): Microscopic examination and comparison of analyses on the standard and test sieves. 171 pp. Illustrated. Five appendices: Appendix A describes the separation and classification of subsieve (−325 mesh) particles (cyclone method); Appendix B—photomicrographs and diagrams.

2100. **The Powder Metallurgy of Zirconium.** COX, G. F. and MILLER, G. L. Symposium on Powder Metallurgy. Dec. 1954. Group 1, 19–29. Institute of Metals, and Iron and Steel Institute.

2101. **A New Method of Determining Grain Size and Specific Surface of Metal Powders.** DERYAGIN, B. V., ZAKHAVEVA, N. N. and TALAEV, M. V. *J. tech. Phys.. Moscow* (*Zh. tekh. Fiz.*), 1955, **25** (5), 881–6. The air-permeability method, full aerodynamic theory and apparatus are described. In comparing the results with those from microscope measurements, agreement was good for copper and iron powders, but poor for aluminium powders which were spiral shaped. A short abstract is given in *J. Inst. Met.*, Dec. 1955, **23** (4), 315.

2102. **Copper Powder.** ELLWOOD, E. C. and WEDDLE, W. A. *J. Inst. Met.*, 1952, **80**, 193–206. A novel and cheap method of producing copper powder is described. Scrap copper is oxidized at high temperature, the oxide ball is milled to a powder, 83% passing a 200-mesh sieve, and the powder reduced to metallic copper in hydrogen.

2103. **Development of Titanium Powder Production. Final Report.** HATCH, A. J., WEBER, E. P. and SCHWOPE, A. D. Clevite Research Centre. Contract DA-33-019-ORD. 1467. 30 Sept. 1955. *Titanium Abstracts Bulletin, I.C.I.*, 1956, **1** (7). Three methods investigated for powdering titanium were ball milling, Wiley milling and crushing of hydrided titanium sponge. The preparation of titanium powder and feed material from scrap and by hydriding sponge, comminuting and then dehydrating, appears to be feasible. The 6% aluminium, 4% vanadium, 90% titanium alloy and others have been synthesized by powder metallurgy. *Nuclear Sci. Abstr.*, **9** (23), 981. 1955.

2104. **Powder Metallurgy.** HUTTIG, G. F. and KIEFFER, R. *Angew. Chem.*, 1952, **64**, 41–54. On p. 47–8, the chemical and physical methods for obtaining powders are described. Size distribution of products are discussed and the effects of ball size are presented graphically. Variables on the particle shape and size. The attainment of an equilibrium distribution by agglomeration or 'reverse condensation' is discussed.

2105. **The Grinding of Metal Powders.** HUTTIG, G. F. and SALES, H. Symposium on Powder Metallurgy, Dec. 1954, Group 1, 8–10. TN 695. Sy 68. Institute of Metals and Iron and Steel Institute. Effects of metal properties and grinding variables on grinding results. Mechanical properties of sintered steel are improved by decreasing grain size of the powder. 6 pp.

2106. **Powder Metallurgy.** JENKINS, I. *Nature, Lond.*, 12 Feb. 1955, **175** (4450), 276–8. Physical properties of a metal powder, including shape, density, surface condition and size distribution of the powder particles have received special study in recent years, and considerable advances have been made in methods of examining these properties. The behaviour of brittle, tough and ductile metals on mechanical grinding leads to the interesting conclusion that, with soft metals, an equilibrium particle size is reached irrespective of the initial size used. This paragraph is included in an appreciation of the symposium on Powder Metallurgy held in London, 1–2 Dec. 1954, by the Iron and Steel Institute and the Institute of Metals at which 50 papers were presented.

2107. **Determination of Particle Size in Powder Metallurgy.** KALISCHER, P. R. *Trans. electrochem. Soc.*, 1944, **85**, 153–62. Four methods are discussed: microscope, elutriation in air, in liquid, and by gravitational fractionation. The last is found to be the best and is very accurate. An improved gravitational fractionation method (Turbidimeter) is presented in detail and recommended for wide use.

2108. **Subsieve Particle Size Measurement of Metal Powders by Air Elutriation.** POLLARD, R. E. *J. Res. nat. Bur. Stand.*, 1953, **51** (1), 17–31, *Res. Ppr*, No. 2428. Particle-size measurements of spherical metal powders by means of the Roller air analyser using samples up to 40 g of powder, were found to be reproducible within approximately $\pm 1\%$ of the original weight of sample, for particle diameters up to 120 microns. The separation limits closely approximated Stokes law ($V=Kd^2$) for diameters of 5–20 microns. For diameters of 20–70 microns, the size limits of fractions conformed approximately to the formula $V=K''d^{1\cdot 4}$. With larger particles the accuracy was uncertain. Reproducible results were also obtained with irregularly-shaped particles, such as those of electrolytic copper powder. However, the accuracy of the calculated size limits was uncertain, no attempt being made to check them by other methods of measurement.

2109. **Determination of Particle Size in the Sub-Micron Range.** SCHUBERT, Y. and KOPELMAN, B. *Powder Metall. Bull.*, 1952, **6** (3), 105–9. (1) Because of reasonably good agreement obtained, either the B.E.T. adsorption method or the X-ray line broadening technique may be used for iron. (2) The iron powder investigated was almost spherical in shape.

2110. **Improvements Relating to the Manufacture of Magnetic Cores from Magnetic Dust.** STANDARD TELEPHONES AND CABLES, LTD. (WESTON, W. K., BUCKLEY, S. E. and

JOHNSTON, T.). *Brit. Pat.* 587138, 1947. Brittle boundary phases are intentionally introduced into tough nickel iron alloys to facilitate conversion to powder, by scattering the molten material, while pouring, by means of a water jet.

2111. **The Design and Operation of Small Mills for Mixing Powder.** SUMMERS-SMITH, D. *Metallurgia, Manchr*, 1949, **39**, 309. Two sizes of ball mills are described, which have been designed to facilitate metallurgical research by powder metallurgy methods, the larger being suitable for mixing samples weighing about 10 g, and the smaller one for dealing with samples of about 1 g. Reference is made to work carried out with these small mills. 6 figs.

2112. **Comparison of Methods of Determining Particle Size Composition of Alumina Powders.** VOLOSEVICH, G. N. and PARKACHEVA, A. I. *Zavodsk. Lab.*, 1955, **21** (1), 69.

2113. **Powdered Aluminium.** WARRING, R. H. *Mech. World*, Aug. 1953, **133**, 350–2. The uses of and processes used for producing various kinds of aluminium powder are described. Spraying molten aluminium for granular material, stamping for flake material and wet ball milling with lubricant, pressing and drying for very fine material.

ORES: GOLD

2114. **The Practical Application of Hydrocyclones in Milling Circuits in Sundry Gold Mines.** ADAMSON, R. J. and MORTIMER, J. H. *See under* Classification.

2115. **Notes on the Application of Hydrocyclones in the West Rand Consolidated Mines Ltd.** ARTHUR, J. A. *J. chem. Soc. S. Afr.*, 1956, **56** (8), 295–99. The results of installing a 27-in., 20° cyclone in the secondary milling circuit for replacing two bowl classifiers and for increasing output are presented in tabular form. [P]

2116. **Non-Assayable Gold—A Fallacy.** ATKINSON, C. W. R. *J. chem. Soc. S. Afr.*, 1955, **55** (10), 243–5. Comments on a paper by Sinclair. Does not admit the fallacy, and gives data for the unaccountable loss of gold when the ore was crushed in a ball mill plant as compared with the same ore crushed in a stamp mill. The respective assays were: for stamp mill, between 100% and 87%; for ball mill, between 75% and 68% gold.

2117. **Classification in Witwatersrand Mills.** BATES, B. R. *Trans. Amer. Inst. min. (metall.) Engrs*, 1926, **73**, 239–52. Classification in milling operations at South African Mines. The author shows in exhaustive trials the importance of control and quality of the feed. His works confirm the advantage of the preliminary reduction in a cascade mill. The importance of classification to obtain efficient tube mill grinding was thoroughly demonstrated, by the use of various types of classifier.

2118. **Recent Progress in Design and Operation of Gold Reduction Plants.** BRITTEN, H. *J. chem. Soc. S. Afr.*, 1955, **55** (12), 313. Large-diameter tube mills and cyclone classifier are important advances. Pebble mills are more economical than steel media. A relatively fine crusher product should be fed (10–15% only on a $\frac{3}{4}$-in. mesh sieve). Speed is about 90% of critical number. Liner wear increases with rev/min.

2119. **The Cyclone as a Gold Concentrator.** FRENCH, J. H. *J. Chem. Soc. S. Afr.*, 1955, **55** (5), 205–11.

2120. **Gold Mining in the Witwatersrand.** KING, A., *et al.* Transvaal Chamber of Mines, Johannesburg, 1949. Chap. 2, Pt. 1, pp. 19–38. Preparation of ore for stamp milling, sorting and crushing. Deals with the use of jaw crushers, gyratory and cone crushers. Illustrations, drawings, tables of capacities and performance. Chap. 3, Tube milling and ball milling. Chap. 4, Recovery of gold by gravity concentration during grinding. Chap. 15, Tables, including a table of approximate launder grades for Witwatersrand ore pulps. [P]

2121. **A Review of Recent Developments in the Use of Hydrocyclones in Mill Operation**

(**Rand Mines**). KOK, S. K. de, *J. Chem. Soc. S. Afr.*, 1956, **56** (8), 281–94. *See under Classification.* [P]

2122. **Some Notes on the Use of the Hydrocyclone on Mines of the Anglo-Transvaal Group.** KOK, S. K. de. *J. Chem. Soc. S. Afr.*, 1955, **55** (4), 159–68. The performance of several sizes of hydrocyclone in the gold reduction plants with various feeds is described and presented in tabular and graphic form. [P]

2123. **Mining and Milling at Amalgamated Banket Areas.** PERRY, E. J. *Mine & Quarry Engng*, 1952, **18**, 218–22. Deals generally with the crushing and ball milling of ore by a goldmining company, Gold Coast Colony.

2124. **Crushing and Grinding of Banket.** WHITE, H. A. *J. Chem. Soc. S. Afr.*, 1929, **30**, 1. Although the paper deals with the crushing of banket, an interesting comparison is made between the energy used to disintegrate the material by various processes and the energy required to shatter the material by impact test. The relative efficiencies based on impact tests are as follows: mine blasting, 0·7%; crushers, 4·4%; stamp batteries, 10·5%; tube mills, 18·6%. (Cf. Bond, 1954, who states that mechanical and blasting efficiencies are about equal.) [P]

ORES: IRON

2125. **Iron Ore Preparation in Germany, 1939–1945.** *B.I.O.S. Final Report*, No. 592. H.M. Stationery Office. For the iron ore at the Hermann Goering Werk, the most economical size reduction ratio at every stage was 2:1. Wet crushing was found to give increased wear on the swing-hammer mill.

2126. **Towards More Pig Iron.** *Iron & Steel, Lond.*, 1953 (3), 81–6. The primary crushing of iron ore by Hadfield roll crusher reduces lumps 4 × 4 ft to −10 in. The secondary crusher reduces the 10 × 10-in. material to 6 × 6 in. size.

2127. **Operation Seraphim.** ANON. *Iron & Steel, Lond.*, 1954, (9), 435. The primary crushing of iron ore for the Queen Victoria blast furnace at Appleby Frodingham, one of the largest in Europe, is done by roll crusher. The rolls, 6 ft diameter, are driven at 180 rev/min by a 200-h.p. motor. When set to 6½-in. clearance, the product provides two fractions, plus and minus 2 in., the oversize being passed to secondary crushers.

2128. **Non Magnetic Taconite Treatment.** ANON. *Min. Congr. J., Wash.*, 1955, **41** (5), 40. The ore is ground to 14 mesh and the product fluidized in a reducing atmosphere at controlled temperature for conversion of a 30% haematite inclusion to magnetic oxide for separation. The ore is quenched in water and so fine grinding is facilitated by the resulting cracking. The further steps are described.

2129. **Differential Grinding of Alabama Iron Ores for Gravity Concentration.** COGHILL, W. H. and DELANO, P. H. *Rep. Invest. U.S. Bur. Min.*, No. 3523, 1940. The iron ore contained quartz grains which it was not desired to crush. The ore was therefore crushed to pass a ⅜-in. sieve by any convenient method, and passed for differential grinding in a rod mill, after trials with a roll mill had given poor results. The rod mill 19 × 36 in. was loaded with only 13% (300 lb) of rods instead of the usual 45% by volume. Space was therefore left for an excess of ore, which was therefore ground partly by attrition. The speed of the mill was less than that for cataracting, so as to avoid crushing the quartz grains.

2130. **Differential Grinding in Cyclone Shown by Screen Tests.** ERICKSON, S. E. *Engng Min. J.*, 1954, **155** (1), 95, 168. After passing $\frac{3}{16}$-in. iron ore 5–10 times through a wet cyclone, analyses showed a beneficiation of about 4% iron (54–58%) in the recovered product. It is suggested that some differential grinding had occurred. The improvement occurred throughout the range of sizes of the recovered material.

2131. **Iron Ore Preparation.** HOWAT, D. D. *Mine & Quarry Engng*, 1953, **19** (5), 144–9. The advantages of sledging rolls for this ore are described.

2132. **Crushing of Iron Ore.** HOWAT, D. D. *Iron & Coal Tr. Rev.*, July, 1948, **157**, 177–88, 239–44. Pt 1. Theoretical considerations. A comprehensive survey of the subject of iron-ore production for blast furnaces is being specially compiled by the author. Pt. 1 deals with theoretical considerations behind present-day crushing techniques, including discussion on the relation between the useful work and size reduction, fracture characteristics, particle sizes and distribution and their influence on crusher design. It is not possible with our present knowledge to determine the useful work done in size reduction.
Pt 2. Practical Aspects. The various types of crushing machinery are discussed, including jaw, gyratory, coarse roll, cone and hammer crushers, comparing the features of each.

2133. **Taconite—A New Market for Coal.** JACOBY, J. W. *Bituminous Coal Research*, 1956, **16** (3), 8–9. A brief description with diagrams of the processing of taconites from winning by flame jet piercing machines to pelleting for the furnace.

2134. **The Grindability of Krivoi Bog Iron Ore.** KARMAZIN, V. I. *Min. J. Spb.* (*Gornyi Zhurnal*), 1952, (8), 31–2. Mathematical and graphical presentation of experimental results.

2135. **A Tertiary Crusher for Soft Home Ores.** LANG, C. *J. Iron St. Inst.*, 1951, **167** (4), 400–39; **168** (2), 164; *Res. Pap. Brit. Iron and Steel Res. Ass.*, No. IN/A/4/51. A critical examination and brief report on a high-speed multihammer crusher for preparation of soft iron ore fines for sintering. This is a double shaft hammer mill with opposite rotating members but not interleaving.

2136. **Present Problems in Our Iron and Steel Industry.** LEFEBRE, A. G. *Publ. Ass. Ing. Fac. Polyt., Mons*, No. 93, 1945.

2137. **Crushing Taconite Ore.** MARTIN, H. K. Proceedings, Symposium, 1947. Institute of Mining and Metallurgy, 1948, p. 68. To enable taconite ores to be used in replacement of Lake Superior ores, it will be necessary to crush the former to 20 or even 5 microns to free the magnetite from silica gangue. At present it is planned to effect a 90% iron recovery and to produce a concentrate containing 64·5% iron by crushing to −325 mesh in four stages, i.e. 60-in. gyratory crushers, 24-in. reduction crushers, 7-in. Symons short head cone crushers, and finally rod, then ball mills, dry in the first three, and wet in the last.

2138. **A Magnetic Reflux Classifier.** ROE, L. A. *Min. Engng, N.Y.*, 1953, **5**, 312–5. Describes the application of this classifier in studying the amount of grinding which is necessary to produce the desired degree of magnetite liberation. Results are given for processing a typical taconite ore.

2139. **Iron Ore.** TAGGART, A. F. *Handbook of Mineral Dressing*, 1945, Wiley & Sons, New York; Chapman & Hall, London. Sect. 2, 134–51. The characteristics and mechanical treatment of iron ore summarized. Flow sheets and summaries of practice at individual U.S.A. mines are presented.

2140. **The Preparation of Iron Ore for Blast Furnace and Open Hearth Use.** WILLIAMS, R. R. Yearbook of the American Iron and Steel Institute, 1948, 368–90. A brief description of an interesting application of the Simons crusher for secondary crushing of ores.

ORES: VARIOUS

2141. **Grinding and Treatment of Minerals.** *B.I.O.S. Final Report*, No. 1356. H.M. Stationery Office, 1948, 61 pp. Some 16 firms were visited and their operations described. 30 pp. of illustrations and drawings. The firms were concerned with manufacture of equipment, with processes or particular materials. The minerals mentioned are: silica, manganese dioxide, barytes; lead, zinc, tungsten and lithium minerals.

2142. **Recent Developments in Mineral Dressing.** 1953, Institution of Mining and Metallurgy. An assembly of the 40 papers (with discussion) presented at the Symposium on Mineral Dressing held in London in 1952 by the Institution of Mining and Metallurgy. The seven papers on the more theoretical aspects of size reduction and size determination are to be found under the names of authors in the appropriate sections. These authors are: Bond, Carey and Stairmand, Dorr and Bosqui, Fairs, Fonteyn and Dijksman, Heywood, Kelsall.

2143. **Ore Dressing Laboratory at the United Steel Companies, Ltd.** ANON. *J. Iron St. Inst.*, Nov. 1948, **160**, 310–14. Equipment in certain firms for experimentation in size reduction methods. The scheme at Swinden House includes crushing, milling and grinding of ores to determine the optimum conditions for the liberation of constituent minerals. Description of the various laboratory pulverizers is given.

2144. **Non-Ferrous Ore Dressing in the U.S.A.** *O.E.E.C. Technical Assistance Mission*, No. 54. 1953, O.E.E.C., Paris. Obtainable from H.M. Stationery Office. Chap. 6, pp. 43–53. Crushing, Grinding and Screening. Deals with general practice and trends in U.S.A. In coarse grinding, there is a tendency to replace smooth crushing rolls by rod mills with wide central discharge working in open circuit and yielding a product from 10 to 48 mesh. For fine product (100–200 mesh) the grate type of ball mill is used in closed circuit with classifiers. Gravity lubrication is used wherever possible for a bank of machines of the same type. Technical appendices, pp. 91–199, for the processing of ores of copper, lead and zinc, feldspar, fluorspar, clay, phosphates, titanium, gold, iron, contain flow sheets, equipment information, and performance data under the above headings for various mines. [P]

2145. **Exploitation of Low Grade Ores in U.S.A.** *O.E.E.C. Technical Assistance Mission*, No. 228, 1954. O.E.E.C. Paris. Obtainable from H.M. Stationery Office. Chap. IV. Grinding. As in crushing, the general trend in grinding seems to be to use units as large as possible since the investment cost per horsepower installed gets lower the larger the unit. Some mill men think that efficiency is higher with increased mill diameter. The largest mills to date are 13 ft long and diameter 12 ft 6 in., driven by 1500-h.p. synchronous motors.

2146. **Recent Developments in Practice at the Sullivan Concentrator.** BANKS, H. R. Symposium on Mineral Dressing, London, Sept. 1952, Paper No. 36. Institute of Mining and Metallurgy. Short description of the operation of the Symons jaw crusher (800 tons per hour) and the subsequent 7-ft Symons cone crushers, then rod mill, transportation and sink-float operation. Published in *Recent Developments in Mineral Dressing*. 1953, Institute of Mining and Metallurgy.

2147. **Experience in the Reduction of Hard Rocks.** BATES, W. H. *Brit. Clayw.*, 1936, **45**, 216. The grinding of quartzite in edge-runner mills is discussed; figures for the rate of size reduction are given. The reduction is by wet grinding and the effects of varying water additions are recorded. Temperature effects are also considered. [P]

2148. **Advances in Milling Methods: Reduction Crushing.** BOWEN, M. W. *Min. Congr. J., Wash.*, Feb. 1942, **28**, 65–6. A general account of methods of crushing ores.

2149. **Crushing and Screening in Mineral Dressing Plants.** BROWN, G. J. Symposium on Mineral Dressing, London, Sept. 1952, Paper No. 11. Institute of Mining and Metallurgy. Selecting the crusher to suit the ore. Illustrations of Nordberg crushers. Recent developments in crushers and screens, and particularly heavy gyratory crushers. The importance of screening. Published in *Recent Developments in Mineral Dressing*, 1953, Institute of Mining and Metallurgy.

2150. **Ore Dressing Studies No. 31. Flotation of Lead-zinc-fluorspar Ores.** CLEMMER, J. B., DUNCAN, W. E., DE VANEY, F. D. and GUGGENHEIM, M. *Rep. Invest. U.S. Bur. Min.*, No. 3437, 1939.

2151. **Approximate Quantitative Microscopy of Pulverized Ores.** COGHILL, W. H. and BONARDI, J. P. *Tech. Pap. Bur. Min. Wash.*, No. 211, 1919, 20 pp. An improved method using the binocular microscope and camera lucida.

2152. **Determination of the Flakiness of Ores.** COGHILL, W. H., HOLMES, O. W. and CAMPBELL, A.B. *Rep. Invest. U.S. Bur. Min.*, No. 2899, 1928. Comparison of grading and shape of two very dissimilar zinc ores, when crushed in rolls, a disc crusher and a ball mill.

2153. **Storke Level. Key to 25 M. Dollar Climax Project.** COOLEY, C. M. *Min. Engng, N.Y.*, 1953, **5** (1), 36–41. One of the largest gyratory crushers in the world is installed at the new Molybdenum mining project—Storke Level, U.S.A. It takes run of mine ore and crushes it to −9 in. Cone crushers reduce this to −⅜ in., which then feeds the ball mills.

2154. **Ore Concentration and Milling.** COUNSELMAN, T. B. *Min. Metall., N.Y.*, 1943, **24**, 59. A general account of the effort at various plants to improve capacity without using scarce materials.

2155. **Milling at Mount Isa.** CUNNINGHAM, K. T. *Proc. Aust. Inst. Min. Engrs*, 30 Dec. 1953 (171). Lead zinc ores and copper ores are treated. An account is given of the milling and other preparation processes, with drawings of the layout. The results of infrasizer analysis are tabulated. Other operating data are tabulated and the ball wear is reported as 1·7 lb/ton of ore for 3-in. steel balls.

2156. **New Ideas in the Preparation of Ore for Milling.** DEAN, R. S. and GROSS, J. *Canad. Chem. Metall.*, 1932, **16** (3), 71–2. Explosive shattering is discussed on the basis of microscope examination of typical mineral sections. Calculations of energy requirements show that the process might be economically competitive with conventional processes and worth consideration.

2157. **Tube Milling (Ball and Pebble Mills).** DEL MAR, A. 1917, McGraw-Hill Book Co., New York. A treatise on the practical application of the tube mill to metallurgical problems. A series of flow sheets is given for stamp mill operation with and without tube mills to follow. The stamp mill is still with us for amalgamating and for a medium-size product, and in combination with the cylindrical tube mill, for cyanide treatment of a slime. Second is the popularity of the conical mill for a product up to 90 mesh, in competition with a tube mill of large diameter and short length, in circuit with a classifier. Third is the deserved popularity of the cylindrical tube mill with varying diameter and length according to the size of feed. 145 pp.

2158. **Ore Dressing Tests and Their Significance. No. 16, Ore Dressing Studies.** Pp. 5–37. DIETRICH, W. E., ENGEL, A. L. and GUGGENHEIM, M. *Rep. Invest. U.S. Bur. Min.*, No. 3328, 1937. Tests were devised to ascertain the essential elements of a preferred ore-dressing treatment that can be recommended for each ore. Sizing tests, float and sink tests, microscopic study, magnetic tests, heat treatment, agglomeration and tabling.

2159. **Present day Grinding.** DJINGHEUSIAN, L. E. *Trans. Canad. Min. Inst. (Inst. Min. Metall.)*, 1949, 52; *Canad. Min. metall. Bull.*, 1949 (450), 555–67; *Chem. Abstr.*, 1950, **44** (4), 1288a. A summary of recent developments, and an analysis of the progress made in grinding. It described the progress on the practical aspects, at the Hollinger Mines, Lake Shore, Flin Flon, Sullivan, International Nickel, Tennessee Copper. Sections deal with mill liners, ball media and ball wear. [P]

2160. **The Importance of Classification in Fine Grinding.** DORR, J. V. N. and MARRIOTT, A. D. *Trans. Amer. Inst. Min. (metall.) Engrs*, 1930, **91**, 109–46. Discussion 146–53. Discusses advantage of closed circuits and particular advantage of bowl classifiers in removing a finished product after primary mills and return of heavy minerals for additional grinding. Flow sheets of copper plants show changes and results due to these changes.

2161. **Climax Milling Practice.** DUGGAN, E. J. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1456, 1942. Description with flow sheets of the milling practice of the Climax Molybdenum Co., Colorado. 14 pp.

2162. **Ore Testing Studies. 1938–9.** ENGEL, A. L. and SHELTON, S. M. *Rep. Invest. U.S. Bur. Min.*, No. 3484, 1940. Primarily ore-dressing studies to provide applicable indications of treatment methods. 34 pp.

2163. **Cyclone Separator may be the Solution for the Fine Ore Problem.** ERICKSON, S. E. and HERKENHOFF, E. *Engng Min. J.*, 1950, **151** (6), 71–3.

2164. **Grinding Investigations at Malmberget.** FAGERBERG, B. International Ore Dressing Congress, Goslar. May 1955, Deutsche Metallhütten und Bergleute e.v. Clausthal-Zellerfeld. *See* No. 1077.

2165. **Review of Fine Grinding in Ore Concentrators.** GOW, A. M., GUGGENHEIM, M. and COGHILL, W. H. *Inform. Circ., U.S. Bur. Min.*, No. 6757, Jan. 1934, 29 pp.

2166. **Treatment Plant Operations at Giant Yellowknife.** GROGAN, K. C. *Canad. Min. metall. Bull.*, 1953, **46** (492), 211–2. Tabulated data for jaw crushers, Simons cone crushers and ball mills are presented, particularly for wear of parts in crushing gold-bearing ores. [P]

2167. **Explosive Shattering as a Possible Economic Method of Ore Preparation.** GROSS, J. and WOOD, C. E. *Rep. Invest. U.S. Bur. Min.*, No. 3268, 1935, pp. 11–19.

2168. **The Hadsel Mill.** HALL, R. G. *Trans. Amer. Inst. Min. (metall.) Engrs*, 1935, **112**, 15–24. Description and advantages in ore crushing. *See* No. 973.

2169. **Current Fine Grinding Practice and Recent Developments.** HATCH, R. *Min. Congr. J., Wash.*, 1942, **28**, 65. A general account of fine grinding of ores. The ball mill is pre-eminent as a fine-crushing medium.

2170. **The Hollinger Crushing Plant.** HOLLINGER MILL STAFF. *Canad. Min. metall. Bull.*, 1953, **46** (497), 551–76. *Trans. Canad. Min. Inst. (Inst. Min. Metall.)*, 1953, **56**, 286–313. The crushing is done by jaw crusher 2900 ft underground, Simons cone crushers above ground (7 and 5½ ft), and ground by a pair of 78-in. diameter by 20 in. Trayler rolls. Data on performance, wear, power consumption costs, dust counts, are presented in tabular form for the crushers, grinders, and all auxiliary equipment, including belting, screens, cyclones, fans, etc. Crushing and grinding plant are enclosed to prevent escape of dust. *See also* McLaren, D. C., *Canad. Min. J.*, 1944, **65**, 363–9. [P]

2171. **Columbite Recovery.** HURST, J. *Chem. Age, Lond.*, 24 June 1955, 1626. The separation of columbite particles from dumps of tin mining refuse has been unprofitable hitherto owing to the clogging of sieves by the carrot-shaped particles of columbite. A new gyratory sieving machine has been developed by Russell Constructions, Ltd. The screen is caused to move in a minute circular orbit, say $\frac{3}{16}$ in. at 1500 c/s, in a horizontal plane. The carrot-shaped columbite particles are caused to rotate on their longitudinal axes and at the same time turn end over end with all bouncing motion eliminated, so that it is impossible for any material to stick in the mesh and cause blinding. A ¼-h.p. motor is used. *See also ibid.*, 19 Dec. 1953, 1273–6.

2172. **Metallurgical Improvements in the Treatment of Copper-Nickel Ores.** INTERNATIONAL NICKEL CO. OF CANADA, LTD., STAFF. *Trans. Canad. Min. Inst. (Inst. Min. Metall.)*, 1948, **51**, 187–98. The advantage of elimination of fines is shown, and the efficiency of classification is discussed. After trials with more than 500 000 tons of mineral, the advantage of several stages over one stage only is shown by (1) a reduction of 30% in steel consumption; (2) an increase in capacity of 15%; (3) a reduction of 13% of power.

2173. **Selection of Ore-crushing and Grinding Equipment.** KENNEDY, J. E. *Min. &*

Metall., N.Y., 1936, **17**, 139–40. Comparison between effects of jaw and gyratory crushers. Reasons why the latter is more effective.

2174. **Fine Grinding Investigations at Lake Shore Mines.** LAKE SHORE MINES STAFF. *Trans. Canad. Min. Inst. (Inst. Min. Metall.)*, 1940, **43**, 299–434. A report on seven years' experimental 'fact-finding' investigations into fine grinding of Lake Shore ores, with special emphasis on tube milling. *See* Nos. 1067 and 1119. [P]

2175. **The Possibilities of Impact Mills.** LEHMANN, H. *et al. TonindustrZtg*, 1951, **75**, 372–7; 1952, **76**, 9–14. *See* Nos. 857–8.

2176. **Grinding Resistance of Various Ores.** LENNOX, L. W. *Trans. Amer. Inst. Min. (metall.) Engrs*, 1918–19, **61**, 237.

2177. **The Evolution of Various Types of Crushers for Stone and Ore and the Characteristics of Rocks as Affecting Abrasion in Crushing Machinery.** MILLER, W. T. W. and SARJANT, R. J. *Trans. ceram. Soc.*, 1936, **35**, 492; *Min. Proc. Instn. civ. Engrs*, 239. Includes discussion on hammer mills.

2178. **Crushing and Grinding Practice, Tennessee Copper Co.** MYERS, J. F. and LEWIS, F. M. *Trans. Amer. Inst. Min. (Metall.) Engrs*, 1943, **153**, 345. It was shown that each type of mill operates best within a limited role, outside of which its employment is not economical. *See* No. 1134.

2179. **The Effect of Increased Classification Capacity at Allenby Concentrator.** NELSON, W. I. and ARME, H. *Trans. Canad. Min. Inst. (Inst. Min. Metal.)*, 1950, **53**, 31. For the same number of grinding units, the production was increased by: (1) increasing the speed of mills; (2) reducing ball size; (3) lowering grade of classifier to obtain maximum settling area; (4) remodelling the classifiers of tube mills, increasing width from 6 ft to 8 ft; (5) introduction of Dorr Classifiers in tube mill circuit as producers of finished product; (6) redirection of feed form classifier. The horsepower consumption per ton improved from 30·8 in 1929 to 23·4 in 1949.

2180. **The Aluminium Industry.** PEARSON, T. G. *Chem. & Ind. (Rev.)*, 17 Nov. 1951, 988–97. Page 991. Bauxite, dried if necessary, passed over a grizzly, thence to a hammer mill, thence to Lupulco mills where it is reduced to 10 mesh, the fines being removed through a cyclone and used.

2181. **Coal Preparation, Pt 2.** PRYOR, E. J. *Colliery Engng*, 1950, **27**, 192–4. The author discusses breakage of ores as regards the liberation of values, avoidance of overgrinding and the removal of the liberated values at an early stage. Methods of separation are discussed.

2182. **Developments in the Science of Mineral Dressing.** PRYOR, E. J. *Times Science Review*, Summer 1954, pp. 17–18. Deals mainly with the principles of flotation, but includes a short section on the importance of the wet-grinding process for releasing the desired minerals and the reactions of new surface with water and surface reagents and in some cases with coating metals.

2183. **Possibilities of Impact Mills in Ore Dressing.** PUFFE, E. *Z. Erzbergh. Metallhüttenw.*, 1950, (3), 41–7, 75–7; *Engng Min. J.*, 1955, **156** (7), 98–100. *See under* Hammer Mills. [P]

2184. **A Study of Grinding Efficiency in Relation to Flotation Practice.** ROSE, E. H. Patino Mines, Bolivia. *Min. J.*, 28 Aug. 1926, 331–8. *See* No. 1141. [P]

2185. **Simultaneous Grinding and Flotation.** SCHELLINGER, A. K. and SHEPARD, O. C. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 2461, 1948. 6 pp. Describes how this process can avoid the overgrinding usual in a conventional ball mill and classifier. States that 90% of the energy is used in useless overgrinding. Overgrinding is detrimental to the flotation process, since overground slime coats the larger particles. Two tables of comparison test results are given and a vertical ball mill combining flotation is

illustrated. Balls from ½ to 1¼ in. diameter about one-third fill the bowl. The balls are moved around on perforated platforms, mounted on a shaft driven from the upper end. Compressed air for frothing enters at the base of the bowl, and other arrangements are made for flotation while grinding. The authors are satisfied that simultaneous grinding and flotation is a feasible process. [P]

2186. **Purpose and Equipment of the Ore Dressing Institute of the Clausthal Mining Academy.** Schranz, H. *O.E.E.C. Technical Assistance Mission*, No. 127, 1953, *O.E.E.C., Paris*. Obtainable from H.M. Stationery Office. The purpose is teaching, the evaluation and improvement of known processes, and a certain amount of applied research for industry.

2187. **Cost Preparation and its Relation to Mineral Dressing.** Swartzman, E. and Djingheusian, L. E. *Canad. Min. J.*, 1952, 73 (1), 51–7; (3), 70–6.

2188. **Metallic Minerals.** Taggart, A. F. *Handbook of Mineral Dressing*, 1945. Wiley & Sons, New York; Chapman & Hall, London. Chap. 2, 1–267. The mechanical treatment of the ores of forty metals is summarized. There are also included summaries of the U.S.A. practice at individual mines providing the information. Flow sheets of complete treatment are presented.

2189. **Elements of Ore Dressing.** Taggart, A. F. 1951, Wiley & Sons, New York, and Chapman & Hall, London. The book deals in 24 Chapters with the practical aspects of ore dressing. Chapters 20, 21 and 22, pp. 341–434, deal with primary crushing, secondary crushing and grinding respectively, with illustrated analysis of the mechanism of reduction in the various types of mill. 577 pp.

2190. **The Hydrocyclone in Manganese Preparation.** (In English.) *Tarjan, G.* (Sopron). *Acta tech. hung.*, 1952, **4**, 135–44. *See under* Classification.

2191. **Modern Ore-Crushing and Classifying Plants.** Tillmann, W. *Stahl u. Eisen*, 1943, **63**, 273. Descriptions and diagrams are presented of two ore-discharging and preparation plants of modern design which have proved to be efficient in practice. One plant discharges, crushes, screens and sinters Swedish ores arriving in lighters, whilst the other deals with ores arriving by rail.

2192. **Hydrocyclones in the Dressing of Ores.** Trawinski, H. *Chem.-Ing.-Tech.*, 1955, **27** (1), 13–17. *See under* Classification.

2193. **Metallurgical Applications of the Dorr-Cyclone.** Weems, E. J. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 3093B; *Min. Engng, N.Y.*, Aug. 1951, 3, 681–90.

2194. **Beneficiation Moves Forward.** Weiss, N. and Michaelson, S. D. *Min. Engng, N.Y.*, 1955, 7 (3), 257–69. The trends in crushing, screening, grinding and classification of ores are included. (1) Multi-stage wet grinding will relieve the burden due to rod milling becoming unfashionable 25 years ago. (2) Preference for limiting rod mill feed to ⅞ in. with 80% passing ½ in. (3) Trend to eliminate closed-circuit features on acc. expense and complexity and use a fourth stage clean-up machine for crushing. This would be a Nordberg Gyradine crusher with a 1-in. to ⅜-in. feed. Various newer and larger crushers and grinders are referred to.

2195. **Impact Crushing for Reduction of Hard Abrasive Ores.** West, W. W. *Min. Engng, N.Y.*, 1952, 4 (6), 563–4. The author describes the use of hammer mills in which both impact and attrition serve to obtain with alumina, quartz and perlite a cubical product with a minimum of fines. Illustration showing impact and attrition zone. Repair costs are not high. The crusher is comparatively new to industry. There is a number of minerals for which this method is not suitable. Fundamentals of impact crushing are considered.

2196. **Increasing Efficiency in Ore Grinding Processes.** Zakhvatkin, V. K. *Min. J., Spb.* (*Gornyi Zhurnal*), 1949, (9), 24.

2197. **Ore Treatment.** ZINC CORP., LTD., and NEW BROKEN HILL STAFF, New South Wales. *Chem. Engng Min. Rev.*, 1953, **45** (2), 50–7. Crushing plant designed to handle wet fines. A general description of crushing and screening plant layout; where reduction is done by successive cone crushers, then by a rod mill and ball mill respectively. The Symons cone-crushers, rod and ball mills are described and some data given.

2198. **Crushing Manganese Ores in Cone Type Crushers.** ZUBAREV, S. N. and DZINCHELASKIVI, K. P. *Min. J., Spb.* (*Gornyi Zhurnal*), 1950 (2), 38–9. The performance results are summarized in six tables. [P]

PAINT AND INK

2199. **Paint Grinding.** *See also under* Grinding Rolls.

2200. **Lacquer Paste Grinding on a Three Roller Mill.** ANON. *Amer. Paint J.*, 1940, **25**, 25.

2201. **An Evaluation of Surface Active Agents in Pigment Grinding.** ANON. *Paint, Oil, Chem. Rev.*, 23 Nov. 1939, 87–9. Some 50 agents are evaluated for effect on the mixing of Titanox C with each of two vehicles.

2202. **English Experiences with Paint Grinding Equipment.** ANON. *Paint Oil, chem. Rev.*, 2 Mar. 1939, 7–9. Discusses the performance of various types of grinding mill.

2203. **Optimum Conditions of Operating Ball Mills.** APPELL, F. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1950 (303), 315–22. A review, including determination of optimum conditions, evaluation of grinding efficiency, operating conditions, characteristics of the vehicle-pigment system (volume ratio of the batch to mill capacity, consistency of the batch).

2204. **Evaluation of Fineness, Gauge, and Paint Film Characteristics based on Particle Size Distributions on Pigment Dispersions.** BAKER, C. and VOZZELLA, J. F. *Paint Oil Chem. Rev.*, 23 Nov. 1950, **113**, 109–20. 54 refs.

2205. **Roll Mill, Pebble Mill and Kneader as Pigment Dispersing Equipment. I–II.** BAKER, C. and VOZZELLA, J. F. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, Aug. 1951, (319), 467–89. A technique is described by which mill pastes, with a wide consistency range, can be formulated to investigate roll mill operation. A comparative study of production capacities of milling methods (pebble mill, roll mill and kneader mill) is described.

2206. **Equipment and Methods for Manufacturing Paint.** BARKMAN, A. *Amer. Paint J.*, 1950, **34** (40), 24, 26, 28; *Off. Dig. Fed. Paint. Varn. Prod. Cl.*, 1950 (308), 630–44; *Paint. Oil Chem. Rev.*, 1950, **113** (16). The author thinks that the laboratory results can be directly translated to plant practice. Dough mixers, roll, ball and colloid mills are discussed.

2207. **Roller Mill Grinding. A review.** BONNEY, R. D. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1944, 237, 345, 358. A summary is given of a number of papers presented before the Federation 1923–44.

2208. **Mixing and Grinding.** F. BOWNES & Co. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1938 (176), 244; *Paint Oil chem. Rev.*, 1938, **11**, 318. Experience with different types of mill.

2209. **Operation of Pebble- and Ball-Mills.** BROWN, H. M. *Paint Manuf.*, 1949, **19**, 187–91. Various types of ball-mill are described and their suitability for making specific paints discussed. When deciding the optimum conditions of grinding, factors such as mill size and lining must be taken into account as well as paint charge, consistency, etc. The following types are included: Buhrstone-lined mill, Porox-lined mill (synthetic silicate), high-speed berylite mill, high-speed chrome-manganese ball mill.

2210. **The Effect of Mixing and Grinding Aids in Relation to Wetting and Dispersion.** Daniel, F. K. *Off. Dig. Fed. Paint. Varn. Prod. Cl.*, 1952 (332), 633–8. The varying behaviour of pigment pastes to which wetting agents are added is considered with special attention to flocculation. Grinding aids may not always prove of benefit, but a drawback. Deflocculating agents are required which will leave about 10% flocculation.

2211. **The Use of Dispersing Agents in Paint.** Daniel, F. K. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1953, 635–42. A discussion of the use of dispersing agents, and of procedures for ascertaining the desirable agent from the numerous compounds suggested.

2212. **Roll Mill Grinding.** Draper, C. R. *Paint Manuf.*, 1943, **13**, 20–1. Hints are given for obtaining maximum output and fineness of grind with minimum power consumption.

2213. **Ball Mills and Ball Mill Grinding.** Draper, C. R. *Paint Manuf.*, 1944, **14**, 7–8. General design features and operation of ball mills (pebbles for white paints).

2214. **Theory and Practice of Single Roll Grinding in the Paint Industry.** Edwards, M. G. W. *Peint-Pigm.-Vern.*, 1953, **29** (1), 30–5. This method of using a loaded surface against a revolving cylinder is compared with the mechanism of two-roll grinding. Diagrams. The former is regarded as film grinding.

2215. **Ball Mills in the Paint Industry.** Engels, K. *Farbe u. Lack*, 1949, **55** (11), 414–20. A critical discussion of the advantages and disadvantages of the use of ball mills for paint production. For large-scale production of paints with reasonable fluidity, these mills are well suited, save labour, solvents and time, and give good consistency of product: but for small scale-production of speciality product, they are impractical. The conditions for most efficient grinding are given in detail. A novel ball mill is described.

2216. **Grinding Bar Roller Mills in the Paint Industry.** Engels, K. *Farbe u. Lack*, 1950, **56** (6), 252–7; (7), 295–9. The advantages of these in paint grinding are discussed.

2217. **Novel Ball Mill.** Engels, K. *Farbe u. Lack*, 1950, **56** (8), 352–5. Experimental data are reported for grinding times for various paints in the novel ball mill previously described in 1949, **55** (11), 414–20. Ball mills in the paint industry. It is shown that yields are much higher in the new mill. It is characteristic of the mill that the efficiency-rotation speed ratio does not show a sharp peak as in the conventional mill, and, in addition, porcelain and steel balls have the same efficiency. L. Schoffel comments on this article; 1950, **56** (8), 356. [P]

2218. **Dispersion of Pigments by Ball and Pebble Mills.** Fischer, E. K. *Industr. Engng Chem.* (*Industr.*), 1941, **33**, 1465–71. Optimum conditions for the operation of steel ball mills for pigment dispersion have been investigated experimentally in mills ranging from laboratory to production sizes. Microscopic examination of the dispersions and the rate of strength development were used as criteria for evaluation. The dispersion rates were correlated with ball size, relative volume of ball and mix charges, and mill diameter. The charge ratios usually recommended depart considerably from optimum milling conditions. By adjustment of the formulation to allow proper cascading of the balls and by maintaining the charge only slightly in excess of the voids in the ball mass, milling times can be shortened. Operating in this way, laboratory mills provide a close indication of the results obtainable with production size mills. [P]

2219. **The Evolution of Mills for Grinding.** Fischer, E. K. *Interchem. Rev.*, 1944, **3**, 91–104. A historical review of the development of grinding mills. Range and utility of various mills are defined in terms of clearance between the mill surfaces, the velocity relative to each other, and the plastic viscosity of the composition being milled.

2220. **Pigment Dispersion with Ball- and Pebble-mills.** Fischer, E. K., Rolle, C. J. and Ryan, L. W. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1948 (287), 1050–65. The

construction and operation of ball and pebble mills are discussed, including the factors of mill speed, nature and load of balls, paths followed by the balls, sizes of balls. Generalized recommendations are made that: (1) mill speed should be 50–65% of critical centrifuging speed; (2) ball load, to give maximum cascading of the balls, should be 40–55% of total mill volume; (3) dispersion volume, 18–20% of mill volume; a charge slightly in excess of one filling the ball voids is most rapidly dispersed; (4) ball size—the smallest practicable considered nature and quantity of charge, with a few larger balls to assist ball mobility.

2221. **New Grinding Machine. (Ink Mill.)** GERSTACKER, L. *Farbe u. Lack*, 1950, **56** (2), 73. A short note on the construction, mode of operation, handling and output of an American ink mill.

2222. **Roller Mill Equipment.** GRANT, W. J. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1949, 296, 599–605. An account of the development of roller mills and advice regarding installation operation and maintenance.

2223. **Working with Roller Mills.** HANTUSCH, O. *Farbe u. Lack*, 1949, **55** (3), 87–9. A description of the adjustments that can be made to roller mills to secure optimum performance.

2224. **Practical Aspects of Pigment Dispersion.** HOBACK, W. H. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1951 (316), 255–9. The dispersion characteristics of a series of TiO_2 pigments dispersed in various media in a mixer and ball mill are presented. It is found that chemical modification of the TiO_2 assists dispersion. Copiously illustrated, and shows effect of pigment type, vehicle and milling on dispersion.

2225. **Roll Mill Technique.** HUMMEL, C. *J. Oil Col. Chem. Ass.*, 1950, **33** (360), 271–7; *Technical Abstracts, Linoleum Research Council*, 1950, (14), 451. This is an important contribution to the study of the mechanics of roll mills used for grinding or dispersion of a pigment into a medium. The inaccuracy of rolls and their bearings are dealt with. Errors incurred are substantial.

2226. **Modern Ball and Pebble Mill Technique.** KENDALL, S. W. *J. Oil Col. Chem. Ass.*, 1932 (15), 66. *See* No. 1113.

2227. **Grinding and Mixing.** KLEINFELDT, H. F. *Amer. Paint J.*, 1951, **35** (41), 68, 70–4. Discusses correct installation and efficient use of ball and pebble mills, listing the variables upon which efficient operation depends. Reviews briefly the recognized methods of mixing, and draws attention to the Abbe Dispersall Mixer, in which a milling action is produced by passing the material through the narrow space between the stator ring and the mixing disc, which breaks up agglomerates, wets the particles and disperses them in the vehicle.

2228. **Milling of Oil Paints and Enamels and Means of Intensifying and Rationalizing the Process.** KOZOLIN, N. A. *Prom. Org. Khim.*, 1940, **7**, 493–9; *Fette u. Seif.*, 1941, **48** (7), 480. A survey of the new types of machines developed in Russia and other countries. Control of milling by photomicrographic examination.

2229. **Mill Gains New Flexibility.** LEHMAN, C. *Chem. Engng*, 1953, **60** (10), 244. The Selective Float-o-Matic ink or paint mill has a floating or fixed centre roll which allows running with equalized pressures or differential pressures between the two roll nips.

2230. **Paint Grinding Balls made of Improved Alloy Cast Iron.** LONGE, K. A. de. *Paint Varn. Prod. Mgr.*, 1950, **30** (9), 17, 22. The use of a martensitic alloy cast iron for the manufacture of paint grinding balls is discussed. Loss in weight after 5000 hours is compared with that of other balls.

2231. **A Study of Dispersion. Correlation between the Variables of a Ball Mill.** MAUS, L. JR., WALKER, W. C. and ZETTELMOYER, A. C. *Industr. Engng Chem. (Industr.)*,

1955, **47** (4), 696–706. The study of the dispersion of a pigment in oil was made to correlate ball mill variables. An equation is developed which permits the construction of a new grinder.

2232. **Principle of Grinding Paint on a Carborundum Stone Mill.** MOREHOUSE, G. H. *Paint Varn. Prod. Mgr*, 1949, **29** (6), 159–63. Stone mills of improved design are efficient production units. Control of consistency of stock, and use of grinding aids effect further improvements.

2233. **Review of Some Mixing and Grinding Equipment.** MOUNTSIER, S. R. Jr. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1951, (315), 233–6.

2234. **A Study of the Optimum Conditions for Pebble Mill Dispersions.** O'NEILL, J. J. F. and FREMGEN, R. D. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, Oct. 1953, 713–40. A discussion of the reasons for aggregated pigment particles and of the methods of dispersing them. The physical characteristics of materials are tabulated. The bulk of the paper consists of discussion and graphic representation of the results of dispersion experiments in pebble mills for many types of pigment, vehicle and solvent. [P]

2235. **The Quickie—A High Speed Ball Mill for the Paint Lab.** ORWIG, B. R. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1954, **26** (356), 830–6. Prepares dispersions in minutes, not hours. Simple to clean; correlates well with production mills.

2236. **A New All-Glass Mill.** PALL, D. P. *Industr. Engng Chem.* (*Anal.*), 1942, **14**, 346. A new mill has been developed, by means of which inks and paints over a wide consistency range can be thoroughly ground without contamination. This new apparatus consists essentially of two truncated glass cones, one of which is fitted inside the other, together with a plunger feed mechanism which forces crudely mixed ink into the annular space between the conical sections, one of which is rotated with respect to the other. For example, the outer section of a ground-glass joint is fitted with a plunger at the small end, and ink forced by a rotating appropriately-slotted stopper. The efficiency of this mill has been tested relative to that of a laboratory 4×8-in. three-roller mill as well as hand milling. Advantages are excellent dispersion and freedom from metallic contamination, with whites and light colours.

2237. **Grinding Processes in the Paint Industry.** PENIGAULT, M. *Peint.-Pigm.-Vern.*, 1947, **23**, 270–8. A review of the viscosity fundamentals and their relation to the mechanism of paint grinding. Classification of grinding operations. (1) Thick pastes, (2) fluid pastes and (3) plastic pastes. A mathematical analysis of each of these aspects is given with graphical representations.

2238. **Improvements in Dyeing.** PLAUSON, H. *Engl. Pat.* 211178, 1922/24; *Chem. Age, Lond.*, 1924, **10**, 299. Pigments wholly or partly inorganic are worked into a state of fine colloidal suspension, showing a definite Brownian movement as in a non-solvent. It is possible to use mineral colours such as graphite, carbon black, lamp black, ochre, etc., by means of high-speed dispersing mill such as a colloid mill.

2239. **Kneader Dispersion of Paints, Enamels and Lacquers.** REDD, O. F. *Paint Oil chem. Rev.*, 1950, **113** (6), 14–16, 18–20. An account of an investigation undertaken to have available information on the wetting and dispersion characteristics of pigments so that dispersion equipment could be evaluated from the standpoint of design, applicability, production rate, etc. Practical examples of paste making are given.

2240. **Fundamentals of Roller Mill Grinding.** VASEL, G. A. *Paint Ind. Mag.*, 1950, **65** (3), 52–4. Factors influencing grinding by roller mills are discussed. A hydraulic controlled pressure mill is available whereby not only can pressure be precisely ascertained, but greater pressures can be exerted. The absolute speed of the mill is important.

2241. **Ball, Cone and Roller Mills.** WAESER, B. *Dtsch. Farberztg*, 1953, **7** (4), 125–33. A description with illustrations of the types of mill suitable for paint and pigments. Descriptions of the Fuller Peters ring ball mill and of an ultra-emulsifier are included.

2242. **A Production Grindometer.** WALKER, W. C. and ZETTELMOYER, A. C. *Amer. Ink Mkr*, 1949, **27** (9), 67. An instrument for fineness of grind of non-volatile inks consists of a surface with tapered grooves 1/1000 in. deep at one end. The marks produced by a scraper indicate oversize particles.

2243. **Investigation of Mechanical Action in Steel Ball Mills.** WHEELER, G. B. *Paint Oil chem. Rev.*, 1948, **11** (25), 12–14. For abstract, *see* No. 1175.

2244. **Formula for Calculating the Capacity of a Roll Mill.** YOSHIDA, J. *J. Soc. Rubb. Ind., Japan.* 1948, **21**, 51–3; *Chem. Abstr.*, 1948, **42** (22), 9227i. For calculating the capacity of a mill, the following formula was derived: $Q = EWVS^n\sqrt{D}$, where Q is capacity, W the length of roll, V the surface speed of the front roll, D the diameter, S the slip coeff. ($S = 100 \times$ (revolution ratio $- 1$)), E a constant relating to the nip, roll temp., etc., n is also a constant. When the formula was applied to actual examples, n was found to be 0·447 and E, $8{\cdot}76 \times 10^{-5}$. Calculated Q, showed fairly good agreement with values obtained from practice.

PEAT

2245. **The Processing of Peat.** Bord na Mona Experimental Research Station, Droicheadnua, Dublin. This station has acquired a reasonably complete list of the literature on this subject and has made many translations from foreign papers. Enquiries on the processing of peat have been invited by the station.

2246. **The Giktorf D.M.G–3. Disc Pulverizer for Peat Samples.** BERESNEVIK, V. V. *Peat Ind., Moscow* (*Torfnaya Promyshlennost*), April 1954 (24/25); *Fuel Abstr.*, Nov. 1954, 4308. A small electrically-driven pulverizer for grinding peat to 2–3 mm. The feed is through the centre of the stationary disc and ground between it and the rotating disc which is eccentric to the extent of 1–2 mm. The discs are shaped as shallow cones with cutting edges radially disposed.

2247. **A Small Hammer Mill Produced by Giktorf.** BYERYESNYEVICH, W. and BORISOV, A. L. *Peat Ind., Moscow* (*Torfnaya Promyshlennost*), 1954 (8), 20.2; Translation 467, Bord na Mona Experimental Research Station, Droicheadnua, Dublin. A prototype of a new design of small hammer mill and the results of its trials are described. Its wide introduction for the preparation of test samples is recommended.

2248. **Production of Crumb Peat for Gasification.** DUBOV, A. B. *Peat Ind., Moscow* (*Torfnaya Promyshlennost*), April 1954 (20/22); *Fuel Abstr.*, Nov. 1954, 4307. The Institute of Peat, U.S.S.R., has developed a machine which mills peat from the surface of the bog, pulverizes it between rollers, forms it into 25-mm pieces by means of a grooved roller and allows it to dry.

2249. **Pulverizing of Peat.** ENGLER, O. and MUTKE, R. International Peat Symposium, Dublin, July 1954, Sect. D1; *Fuel Abstr.*, Dec. 1954, 5378. Pulverizing tests were first carried out on two types of Irish milled peat, a Kramers mill being chosen in preference to a ring and roller mill. The power consumption was found to increase with decrease in particle size of the pulverized product, and decrease with increased mill beater speed. It also depends on the peat quality, fibrous peat being more difficult to grind. To determine the approximate maximum particle size for combustion, firing tests were carried out with German sod peat ground to 50×50 mm size in a Kramer mill. Details are given of the pulverizing mills, fuel feeding equipment and other sections of plant.

2250. **The Raw Peat Macerator of the Temp–2 Excavator.** TROIB, E. G. *Peat Ind., Moscow* (*Torfnaya Promyshlennost*), 1953, (3), 24–6; Translation 408, Bord na Mona Experimental Research Station, Droicheadnua, Dublin. Comparative data on macerators of the Ragov and Temp Excavator, with respect to some physical properties of the final product.

PIGMENTS, CHEMICALS, DYESTUFFS

2251. **Plant and Equipment.** ANON. *Chem. and Process Engng*, 1953, **34** (4), 115. This water-cooled mill suitable for fine chemicals, pharmaceuticals and anti-biotics is provided with a swing hammer working against a series of interchangeable screens which grade the material down to 200 mesh. Various sizes and outputs and interchangeable parts are noted. Made in the United Kingdom.

2252. **Chemical Engineering at the British Industries Fair.** ANON. *Chem. and Process Engng*, 1953, **34** (5), 143. A description of the Intermediate Atomill, especially suitable for chemicals, colours, cosmetics, etc., driven by a 10-h.p. motor. Material is pulverized by 10 hammers and heat-treated steel liners.

2253. **Micro Grinder.** *Chem. and Process Engng*, 1955, **36** (5), 188. A multi-stage hammer mill suitable for dyestuffs, pharmaceuticals, etc.

2254. **Colloid Mills. Grinding experiments with dyestuffs.** Microfilm of German Documents. Obtainable in microfilm or photostat form from Lending Library Unit, D.S.I.R. Ref. FD 1157/50, Frames 2460–76.

2255. **Examples of the Application of the Pipette Method with Special Reference to Fineness Investigations of Mineral Pigments.** ANDREASEN, A. H. M. and BERG, S. *Angew. Chem.*, 1935, **48**, 283; Beiheft No. 14.

2256. **Study of Factors Affecting Grinding Efficiency in Ball and Pebble Mills.** BALTIMORE PAINT AND VARNISH PRODUCTION CLUB. *Amer. Paint J.*, 1948, 33 (6), A20–1. In laboratory experiments a mill running with a ball/charge ratio of 1 – 0·93 gave best results, but on a plant scale 1 – 1·2 was best.

2257. **The Fineness of Grinding of Pigments.** CAMPBELL, G. A. *Chem. Age, Lond.*, 1934, **31**, 347; *J. Oil Col. Chem. Ass.*, 1934, **17**, 387. A criticism of the method of specifying fineness.

2258. **Novel or Improved Device for Use in Grinding Pigment or Other Material.** DICKINSON, W. H. *Brit. Pat.* 611583, 1949. Two tapered drums are positioned so that the inner rotating drum can be adjusted to regulate the grinding pressure between the inner and outer surfaces.

2259. **Dispersion of Pigments in Ball and Pebble Mills.** FISCHER, E. K., *Industr. Engng Chem. (Industr.)*, 1941, **33**, 1465–71. Optimum conditions for dispersion in ball and pebble mills. *See under* Superfine Grinding.

2260. **The Microscopy of Paint and Rubber Pigments.** GREEN, H. *Chem. Metall. Engng*, 1923, **28**, 53. Apparatus used and examples of dispersion are given.

2261. **Grinding of Dry Pigments.** KUNZE, E. *Farben-Chem.*, 1938 (9), 189–91; *Paint Oil Chem. Rev.*, 1938, **11**, 319. The use of edge mills, and precautions to avoid colour changes with different types of pigments, are described.

2262. **Grinding of Dye Pigments.** KUNZE, E. *Paint Varn. Prod. Mgr*, 1941, **21**, 124.

2263. **Jet-milled Pigments.** MOORE, C. W. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, 1950 (304), 373–80. In jet milling, particles are reduced in size by impact and rubbing between the particles themselves; the mill itself has no moving parts, the particles being carried in an elastic fluid stream travelling at about 300–600 mile/h. about a doughnut-shaped tube. It is claimed that this method reduces the individual particles to a much finer size, and that the grinds may be controlled to give high uniformity, though they are not adapted commercially for the ultra-fine size (under 1–2 microns average particle size). Particles produced in this way tend to be similar in shape, and to be smooth ovals or spheroids, without cracks and jagged edges. This has reduced oil absorption. Further, in passing through the jet mill, pigments lose most of their

entrained and absorbed moisture, and, it is thought, the surrounding molecular layer of gas and moisture too.

2264. **The Best Particle Size.** OSTWALD, W. *Farbe*, 1921 (11), 1–12. A discussion on the factors concerning particle size of pigments and their behaviour towards light and the other paint ingredients.

2265. **Applications of Chemical Engineering in the Fine Chemicals Industry.** PEEK, W. C. *Chem. & Ind.* (*Rev.*), 10 Mar. 1956, (10), 159. The Apex comminuting mill is described and illustrated. It is a very high-speed mill revolving at several thousand rev/min. Change from knife-edge action to hammer-face action is made by reversing the direction of the motor. The special construction and controls contributing to convenience and safety are described.

2266. **Ball Mills for Wet Grinding of Pigments.** PROMNITZ, O. Sen. *Farberztg*, 1936, **41**, 136; *Chem. Abstr.*, 1936, **20**, 2050; *Paint Oil chem. Rev.*, 1936, **9**, 126. Mathematical discussion of the relations of time, quantity of balls and material, and total volume. The advantages are emphasized of filling the mill nearly half full of balls and then running in the wet feed until the mill is nearly three-quarter full.

2267. **Improvements in or Relating to Grinding Mills.** ROBINSON, E. S. & A., LTD. (NICHOLAS, F. P. and PEGG, C. E.). *Brit. Pat.* 646526, 1948. Dyestuff pigments or pastes are ground between two frusto-conical members. *See under* Colloid Mills.

2268. **The Fine Grinding of Colours and Chemicals.** STAPLETON, W. A. *Crush. & Grind.*, 1934, **2**, 157–60. The modern methods of combining grinding and pulverizing systems with air separation are described.

2269. **Preparation of Colloidal Mineral Colours.** TRAVIS, P. M. *Bull. Amer. ceram. Soc.*, 1937, **16**, 467. A new method of superfine grinding by the use of compressed air is described in outline. By this method, mineral pigments can be broken down to particles of 10 microns or less at low cost. The unit is completely automatic. A method and apparatus are also described for measuring particle sizes below 325-mesh, or 44 microns.

SAND, QUARTZ, GLASS

2270. **Fine Grinding Small Ceramic Parts.** ANON. *Ceramic Ind.*, 1951, **57** (2), 65. Some recommended procedures are given for preparing mineral products such as glass, quartz, porcelain and synthetic sapphire for grinding. Procedures are suggested and notes are given about grinding media.

2271. **Disintegration of Lumps in Baked Sand.** *Fonderie*, April 1952 (75), 2898–2902. Illustrated survey of equipment available for use in reclaiming used sand.

2272. **The Physics of Blown Sand.** BAGNOLD, R. A. 1949, Methuen & Co.

2273. **Fine Grinding of Glass in Various Types of Mills.** BISCHOFF, F. *Chem.-Ing.-Tech.*, 1953, **25** (4), 196–8. Experiments were carried out to compare the preparation of ground glass of 10 microns and under, in grinding machines, vibratory mills and ball mills. The degree of pulverization in relation to grinding time was analysed and the results presented graphically as Rosin–Rammler–Bennett diagrams. Laboratory results showed the performance as judged by the fineness attained in equal times to be in the order: grinding machines, vibratory and ball mills, the last two differing less from each other than from the first. 22 refs. [P]

2274. **Production of Graded Glass Sand by Grinding and Classification.** FINE, M. M. *Min. Engng, N.Y.*, 1950 (2); *Trans. Amer. Inst. min.* (*metall.*) *Engrs*, **187**, 385. In a laboratory study of grinding and classification of silica sand, a satisfactory means of producing the medium-fine specification sand desired by producers of flint-glass containers was developed. The best procedure consisted of ball-mill grinding and

double classification, which gave a properly-sized sand containing less iron than the feed. 4 figs., 8 tables.

2275. **The Use of Hammer Mills in the Glass Industry.** JOBKES, J. *Glastech. Ber.*, 1949, **22**, 407; 1950, **23**, 1507. *See under* Hammer Mills.

2276. **Hammermills for the Reduction of Sandstone.** KALPERS, H. *Industrie der Steine und Erden*, 1953, **63** (6), 73–4; Abstract in TonindustrZtg, 1954, **78** (3/4), 62. Description of rebounding mills which are still being developed with outputs of 2–250 tons per hour with a power supply of 4–150 h.p. The mill is suitable for limestone, burnt lime and other industrial minerals. Cubical shape is characteristic of the product.

2277. **Investigation of Sand Grinding and Calculations for Equipment.** NEVSKII, B. V. *Min. J., Spb.* (*Gornyi Zhurnal*), 1950, (10), 24–6. Results are tabulated of the experimental work on disintegration in a tumbler mill. 3 refs.

2278. **Rod Mill brings Sand Production into Balance.** NORDBERG, B. *Rock Prod.*, 1953, **56** (10), 101–4. *See under* Rod Mills.

2279. **Dorr Mill. Experiences with the Dorr Mill in grinding quartz and flint for pottery purposes.** ODELBERG, A. S. W. *Trans. ceram. Soc.*, 1922–3, **22**, 1–11.

2280. **The Milling of Pottery Materials and its Control.** RILEY, A. H. *Trans. Brit. Ceram. Soc.*, 1939, **38**, 561. The cylinder grinding of flint is discussed.

2281. **Investigations into the Sieve Analysis of Sands and the Presentation of the Results.** SCHNEIDERHOHN, P. *Neues Jb. Miner.*, April 1953, **85**, 141–202. 8 refs.

SEAWEED

2282. **The Scott-Rietz Disintegrator.** *J. Sci. Food & Agric.*, Nov. 1956, 705–10. *Facts F. Ind.*, Dec. 1956, No. 573. In the disintegration of seaweed, a prebreaker crushes the stones, which fall out as the seaweed is milled by rotating hammers surrounded by a screen of abrasion-resistant steel through which the pulverized mass is passed. This mill is particularly appropriate for materials such as seaweed.

SEED CRUSHING

2283. **Seed Crushing.** DEAN, D. F. *Oil Col. Tr. J.*, 1941, **100**, 449–50. A general description of seed crushing usually between rolls 5 high, with heating to coagulate the albumen, and steaming when necessary. The American hydraulic press process is briefly described.

2284. **Effect of Moisture on Grinding of Tung Kernels, and Solvent Extraction of Meal.** FREEMAN, *et al. Oil & Soap*, 1944, **21**, 328–30. The efficiency of extraction of oil can be materially increased by vacuum drying the kernels beforehand. The most efficient grinding is at from 6% to 9% moisture content. Above 9% moisture, the efficiency of grinding and therefore of extraction decreases. Tabulated data are given.

2285. **Grinder for Material in Suspension.** NEWELL, C. B. and VINCENT, E. R. *U.S. Pat.* 2496017; *Off. Gaz. U.S. Pat. Off.*, 1950 (5), 1258. For general purposes but particularly intended for flax and other oil-bearing seeds. Capable of being adapted as a small portable grinder. The solvent for the oil can be used as the fluid medium, the grinding taking place by rotation of cutting elements mounted on a vertical shaft in close clearance with cutting or shearing elements surrounding. Provision for removal of the liquid and solid is made.

SUGAR

2286. **Sugar.** *Edg. Allen News*, 1953, **32** (373), 145–48. Modern sugar crushing mills consist of six units of three rollers each, 37 in. diameter by 84 in. long. These achieve a juice extraction of 96–97%. The rollers are of grooved cast iron. Each mill

is driven by a 600-h.p. steam turbine. The rolls revolve at 3–4 rev/min. The Mirlees crusher is illustrated, together with an illustration of the grooves being machined.

2287. **Experimental Attempt to Determine a Mechanical Theory of the Crushing of Sugar Cane.** BULLOCK, K. J. *Proc. Qd. Soc. Sug. Cane Tech.*, 1953 (20), 161–7. Details of equipment are given in *Sug. Ind. Abstr.*, May 1953, p. 88.

2288. **Grinding Capacities of Sugar Cane Mills.** CABRERA, J. W. *Trans. Amer. Soc. Mech. Engrs*, 1955, 77 (5), 485–95. Presented at The International meeting of the American Chemical Society, Mexico City, March 1954. The paper describes and presents in tabular and graphic form the effects on performance of the cane characteristics, premilling preparation, mill and human element variables. Conclusions are elaborated in nine paragraphs. 8 pp., 8 tables, 22 graphs. [P]

2289. **Standardization of Sieves and Determination of Grain Size of Granulated Sugar.** JOHNSON, J. R. and NEWMAN, J. S. (Amalgamated Sugar Co.). *Analyt. Chem.*, 1954, **26** (11), 1843–6. Rapid 2-sieve procedure gives information from which average grain size and uniformity of grain size of crystalline products can be seen at once. Two-sieve calibrating methods described, 3 illustrations, 3 tables, 4 refs.

2290. **Evaluation of Sugar Cane Varieties. A Study of Milling Characteristics.** SCHAFFER, F. C. *Bulletin* No. 2, Louisiana State University, Agricultural and Technical College, Engineering Experimental Station, Baton Rouge, 1954. Pt 1. Summary of results for seasons 1950–51. Pt 2, by D. Harlan *et al.*, Summary of results, 1952. Results are presented of determinations of the characteristics of new varieties of cane before release for commercial production.

2291. **Rules for the Operation of Powder Mills.** WEGNER, A. *Zucker*, 1953, **6**, 418–20. The operation of sugar mills and precautions against explosions, under thirteen headings. Revised regulations are given.

SULPHUR

2292. **Sulphur Grinding.** ANON. *Chem. and Process Engng*, 1952, **33** (6), 323. Sulphur generates electric charges, melts under heat and tends to clog. The usual grinder is the pinned disc type. Hardening on the pins entails changing after about 4 hours' use. The Rema ring-roll mill (British Rema Manufacturing Co., Ltd.) avoids these disadvantages. It is used with an air separator with oversize return.

2293. **The Grinding and Air Separation of Sulphur.** DAVIS, J. *Edg. Allen News*, 1952, **31** (362), 193–5. Sulphur is easy to break down, but the dust is liable to explosion. Totally-enclosed hammer mills or pin mills have been used for some time, but the ring-roll mill in conjunction with a classifier is finding favour. Means of fire prevention are described.

2294. **Screw Crusher Solves Problem for Freeport.** GUSTAFSON, A. A. *Min. Engng, N.Y.*, 1950, **2**; *Trans. Amer. Inst. min. (metall.) Engrs*, **187**, 1026; *Int. chem. Engng*, Mar. 1951, p. 130. Ton blocks of sulphur are reduced to conveyor size by feeding along a screw in a trough and forced against teeth secured to the side of the frame. Details of manufacture from boiler plate, etc.

WHEAT, FLOUR

2295. **Cast Magnesium Rotor Stands High Speeds, Shocks, Stresses.** *Amer. Foundrym.*, Aug. 1951, **20**, 51–2. A cast magnesium alloy rotor has been used in a flour mill. It travels at 25 000 ft/min. 20 steel crusher bars inserted in the periphery exert a radial load of 3800 lb each. Yet the maximum stress at any point is limited by the ribbed design to 2000 lb/sq. in. The cast rotor has given a satisfactory performance.

2296. **Whole Wheat Ground on the Spot by a Portable Stone Mill.** LEE ENGINEERING

Co. Staff, Milwaukee. *Food Engng*, Oct. 1954, **26**, 61. A portable miniature mill has been designed for grinding small batches of grain for special purposes, e.g. for whole wheat bread. It can produce 60 lb/h of finely-ground flour from a hopper containing 200 lb of cleaned grain. A sifter is provided for removing coarser particles if desired. The grinding is effected between two horizontal carborundum stones, grooved and adjustable. The power input is adjustable quite simply according to hardness of grain and rate of feed. The mill is mounted on castors for mobility and is 5 ft 7 in. high, and can pass through a doorway. Flour can be produced daily and so avoids oxidation of the germ.

2297. **Milling Technique Investigations.** *Getreide u. Mehl*, 1952, **2** (4), 41–2. The bran separator in modern processing. Report for 1951/52 of the Bundesanstalt für Getreide Verarbeitung, Detmold.

2298. **Milling with the Hiddema Mill.** *Getreide u. Mehl*, 1953, **3** (4/5), 8. The results of researches are: (1) the power requirements are less for the Hiddema Mill than for normal mills but this mill is more sensitive to all variations in milling conditions; (2) that a lower output from the ribbed mill is not compensated by an improved quality.

2299. **Grinding Investigations.** Anon. *Getreide u. Mehl*, 1953, **3** (4/5), 31–3; 1952/3 Report of the Institute for Grain Investigation, Detmold, Germany. A comparison between European and American interpretation of results. Grinding experiments with the Hiddema-Equipment. Graphical representation of moisture changes during grinding. The Rosin–Rammler–Sperling method for evaluating sieve analyses.

2300. **Milling Investigation.** *Getreide u. Mehl*, 1954, **4** (5/6), 40–2. Laboratory investigation has two purposes: (1) to assess the quality of product in large-scale production on the basis of examination of small samples; (2) to determine the grindability of grain. Results of investigations are tabulated for German and American wheats and for wheat dried by the new air turbulence methods.

2301. **Rotary Flour Mill.** *Bull. Wash. St. Inst. Tech. Div. industr. Res.*, No. 206, April 1950. A high-speed rotary mill in which the entire wheat berry is ground to an exceedingly fine flour; the working surfaces carry serrated steel blades.

2302. **Control of Flour Milling from Temperature Recordings of Product.** Atkinson Milling Co., Minneapolis. *Chem. Processing*, Jan. 1954, pp. 56–7. *See under* Automatic Control.

2303. **Flour Milling.** Farmer, W. T. *Proc. chem. Engng Gr. Soc. chem. Ind., Vict.*, 1950, **32**, 1–12. A comprehensive illustrated account of wheat processing from reception and storage to dispatch of the finished flour.

2304. **Laboratory Milling Investigations with the Buhler Automatic Equipment.** Flechzig, J. *Getreide u. Mehl*, 1953, **3** (6), 44–8. (1) Description of the Buhler Automaton. (2) Experimental procedure. (3) The evaluation of results. (4) Reproducibility of results. 12 refs.

2305. **Particle Size of Flour.** Gwillim, J., Ltd. *Milling*, 23 and 30 Jan. 1954, 101, 125–6. *Facts f. Ind.*, 1954, 7 (2), 6–7. The average size of flour particle is normally in the 100–150 micron range, with a protein content of about 10%. In tests with a roller particle size analyser, flour of 38–46 microns shows a protein content of over 13% and gives a larger volume loaf. Gwillim of Petworth produces a flour of which 50% of the particles are smaller than 30 microns and none larger than 100 microns.

2306. **Flour Mill Machinery for Export.** Haltmeier, O. *Progressus*, 1952, **4** (E6), 40–6. A description illustrated, of flour mill machinery with particular reference to crushing and grinding machinery, i.e. the various types of rolls used.

2307. **Grindability of Wheat in Relation to the Variety.** Lein, A. and Flechzig, J. *Getreide u. Mehl*, 1956, **6** (1), 1–4. Eight winter varieties of wheat were tested for grindability and for many other properties and the results tabulated.

2308. **Grooved Rolls and Grinding.** POVEY, D. W. *Northw. Miller.* (Milling Products Sect.), 1953 (150), 23, 250. A general review of the influence on grinding results of the design features of grooved rolls.

2309. **The Performance of Roller Mills.** PRATIQUE, J. *Bull. Ec. franc. Meun.*, 1952, **131**, 175. The quantitative relations between the amount of feed and speed of rolls with regard to amount of hulling and yield of crushed product have been investigated. Derived curves and expressions have been evaluated.

2310. **Special Applications of Grinding Machines.** SCOTT, R. A. *Chemical Engineering Practice*, Vol. 3, Chap. 5, pp. 109–27. Butterworths Scientific Publications, 1957. The arrangements and applications of roll crushers, especially fluted roll crushers for the reduction of grain to flour, are described and illustrated. Applications of millstones to corn grinding are discussed, attrition mills and hammer mills are also discussed in relation to flour milling and similar reduction. 6 refs.

2311. **The Grindability of Wheat.** SEEBORG, E. F. *Northw. Miller.* (Milling Products Sect.), 1953, **10** (1A), 249; abstract in *Getreide u. Mehl.*, June 1953, 48. Hard and soft varieties were compared, optimum moisture content investigated, and an expression was derived connecting the five characteristics investigated.

2312. **Particle Size of Powders.** SPEIGHT, J. *Milling*, 1953, **121** (16), 456. Its influence on the system of flour manufacture. The adoption of flour of very fine particle size might bring about a change in the system of flour manufacture. A special reference to the importance of air power is made.

WOOD FLOUR, WOOD PULP

2313. **Automatic Grinding of Wood Pulp in Rollers.** BONDER, M. P. and JANISHEVSKI, N. P. *Pap. Industry, Moscow* (*Bumashnaya Prom.*), 1953, **28** (10), 9–13. Describes the operation of various grinders. Graphs, diagrams.

2314. **Groundwood Studies: 2. Effect of process variables on grinding mechanical pulp.** HOLLAND, W. W. *et al. Proc. Canad. Pulp Pap. Ass.*, 1935, **96.**

2315. **Groundwood at 5400 Surface feet/min.** JONES, J. B. and HOLLAND, W. W. *Pulp Pap.* (*Mag.*) *Can.*, 1942, **43**, 141–4. Experimental work at the Forest Products Laboratory, Montreal, on mechanical pulping at stone peripheral speeds of 5600 ft/min., provided data from which the following conclusions were drawn: (1) production is directly proportional to speed; (2) unit energy consumption is independent of speed; (3) no measurable changes of pulp characteristics were observed. Four tables of results. The data were collected with a 15 × 30-in. stone in a three-pocket grinder.

2316. **Improvements relating to the Production of Wood Flour.** STALINOV, SAVONY (Czechoslovakia). *Brit. Pat.* 647282, 1947/50. For the purpose of retaining the cell structure, the wood is fed to the grinding element (disc, drum), so that the fibres lie parallel to the axis of rotation of the grinding element, the latter being characterized by the provision on the surface of sharp sand in the form of needle-like grains, and a speed of 2300–3300 rev/min. The conveyor to the grinding element is illustrated.

MATERIALS, VARIOUS

2317. **Grinding and Treatment of Minerals in Germany, 1939–1945.** *B.I.O.S. Final Report*, No. 1356. H.M. Stationery Office. Describes the paste conditions for grinding barytes in a ball mill, down to less than 2 microns, pp. 16–18, 31–2.

2318. **Swing Hammer Mills.** ANON. *Chem. Age, Lond.*, 26 Mar. 1955, 745. A description is given of British J.D. swing hammer mills for the reduction of a large range of materials, including roots, bark, copra, cork, corn cob, fruit peel, paper, peat, straw, town's refuse, wood refuse and tobacco. The mills have been applied as primary units

and in multi-stage milling. The hammer can be used in four positions so as to utilize four wearing edges. Capacities 10–250 tons per hour. Product: 80–90% through ⅛ mesh in one operation.

2319. **Micro Grinder.** *Chem. and Process Engng*, 1955, **36** (5), 188. A multi-stage hammer mill grinds dyestuffs, limestones, gypsum, cocoa, resins, pharmaceutical products. Capacities from ½ to 5 cwt/h from 1 to 25 microns, i.e. 325 mesh and finer. Machine requires minimum maintenance, little floor space, suitable for rapid cleaning where changes of product are frequent.

2320. **Pulverizing 200 Process Materials.** ANON. *Chem. Metall. Engng*, 1938, **45** (2), 241–2. A tabulation of the answers of 43 manufacturers of pulverizing equipment when asked 'Which of these materials has been successfully ground by your equipment?' [P]

2321. **Pulverizing Light Materials.** *Edg. Allen News*, 1953, **32** (368), 31–3. Description, with diagram, of a high-speed multihammer mill, suitable for pulverizing light materials, as listed, from wood refuse, shellac to chalk and asbestos.

2322. **An Investigation into the Change in Volume of Various Crop Materials by Chopping Them.** Tech. Memo. No. 60, National Institute of Agricultural Engineering, 1952.

2323. **Investigation into the Comparative Chop Lengths of Crops Chopped by Three Types of Stationary Chopping Machines.** Tech. Memo. No. 63, National Institute of Agricultural Engineering, 1952. The machine was a cylinder fitted with sharp knives rotating inside a housing fitted with interleaving blunt knives. A table gives data relating power consumption with chop lengths.

2324. **The Graphic Representation of the Size Distribution of Fly Ash.** BRAUKMANN, B. *TonindustrZtg*, 1954, **78** (13/14). *See under* Size Distribution.

2325. **The Properties of Calcined Alumina.** CARRUTHERS, T. G. and GILL, R. M. *Trans. Brit. Ceram. Soc.*, 1955, **54** (2), 69–81. Pt II. The behaviour of calcined alumina during fine grinding. The mode of breakdown was different for the mono-hydrate and tri-hydrate types for the lower calcination temperatures from 1200°C onwards, but as the calcination temperature was increased both types became similar to one another. Until at 1700°C their behaviour on grinding resembled that of fused alumina. Comparison of surface area values indicated that the grinding process consists largely of a breakdown of aggregates. The behaviour on grinding therefore depends on the type of hydrate and on the conditions of calcination.

2326. **Tumbling or Barrel Finishing.** COX, H. Technical Information Service, National Research Council, Ottawa, Ref. No. 33, Nov. 1953. An account of the various methods of finishing small parts by tumbling. The media used and the results obtained. Extensive bibliography. 7 pp.

2327. **Talc.** EUGEL, A. E. J. *Min. Engng, N.Y.*, 1949, **1**; *Trans. Amer. Inst. Min. (Metall.) Engrs*, 1949, **184**, 345. The Wheeler mill and the micronizer have been applied to the grinding of talc to 1–20 micron size.

2328. **Unusual Techniques in Grinding. (Lead Oxide.)** FOOTE, J. H. *Chem. Engng Progr.*, 1953, **49** (2), 71. Done in a ball mill with a dustless discharge housing and controllable air draught. The charge is lead balls or slugs only. The flakes detached during grinding become oxidized with the heat developed (at 250°F). Further heat is developed and the mill operates between 300° and 400°F. The outside of the mill is water cooled if necessary, the cooling being controlled by a thermostat at the discharge end of the mill. The product is 80% lead oxide and 20% metallic lead, not pure enough for chemical litharge but suitable for battery plates.

2329. **Types of Grinding Mills.** FOOTE, J. H. *Chem. Engng Progr.*, 1953, **49** (2), 72.

It might be well to note that it is almost a physical impossibility to develop free-flowing fibrous powders in impact pulverizers. If such a product is required, it is necessary to use ball mills or similar equipment.

2330. **A Comparison of Size Determinations of Duplicate Samples of Fly Ash.** Holton, W. C. and Reynolds, D. F., Jnr. *Combustion, N.Y.*, Aug. 1954, 41–6; abstract in *Battelle Technical Review*, 1954, 3 (11), 112. A deviation of 10–15% points to the need for some standardization of methods.

2331. **Determination of the Specific Surface of Barium Sulphate. Comparison of Results by Different Methods.** Jopling, E. W. *J. appl. Chem.*, 1952, **2** (11), 642–51. *See under* Surface Area Determination.

2332. **The Estimation and Control of the Efficiency of Chocolate Refining Operations.** Kelleher, J. *British Food Manufacturing Industries Research Association Scientific and Technical Surveys*, No. 29, July 1956, 19 pp. The degree of comminution of the sugar and cocoa particles is one of the factors which most markedly affect the palatability of chocolate. As part of the investigation into the comminution and particle size of chocolate ingredients, the classical theories and Bond's third theory were studied and it was shown how they may be derived from the same mathematical basis. Two further methods for the assessment of power requirements based on Bond's law are proposed, and an example is given of the application of the three laws to a practical refining operation. The advantages of closed circuit grinding are discussed. 21 refs.

2333. **Chemical Engineering Techniques.** Laner, E. E. and Heckman, R. F. 1952, Reinhold Publishing Corporation, New York, pp. 133–5. Reduction of fibrous materials. These often resist efforts to reduce them to uniform size, e.g. rubber, rags, paper, plastic scrap, leather, wool, bark and agricultural wastes. Tearing or cutting with knives is effective and pre-treatment such as cooking or steaming under pressure are effective and reduce energy requirements and wear. Hammer mills, knife cutters, saw-tooth disintegrators, slicers (for beet) and other specialized machines are used. Explosive disintegration (the Masonite process) is successful, but chiefly for wood waste (stumps, etc.).

2334. **A New Pulverizing Process for Agricultural Products.** Lengelle, M. *Industr. agric.*, 1954, **71** (7/8), 617; *Getreide u. Mehl*, 1955, **5** (1), 6–7. An air attrition pulverizer is illustrated but not described. Its advantages in use are presented.

2335. **Unsolved Problems in the Production of Chocolate.** Lipscomb,, A. G. *Chem. & Ind. (Rev.)*, 6 Nov. 1954, 1369–76. Methods of testing the particle size of ground and conched cocoa are described, and the Bahco classifier (centrifugal) is illustrated. Complete particle separation into eight grain sizes need not exceed two hours.

2336. **The Effect of Very Fine Grinding on the Crystal Structure of Mica Minerals.** MacKenzie, R. C. and Meldau, R. *Ber. dtsch. keram. Ger.*, 1956, **88** (7), 222–9. Muscovite and vermiculite were ground wet and dry for 24 hours, and the products examined chemically, thermally, spectroscopically, with X-rays and by microscope. Results of examinations agreed that there was less attack with wet grinding, that with dry grinding the particles tended to break in all directions, whereas with wet grinding the tendency was to break along the laminae. After 24 hours' dry grinding, both muscovite and vermiculite product proved to be rounded particles under microscope examination.

2337. **Effect of Grinding on Mica.** MacKenzie, R. C. and Milne, A. A. *Clay Min. Bull.*, July 1953, **2** (9), 57–62. The effects of long grinding on muscovite, biotite, and vermiculite are described. Anomalies in behaviour are referred to.

2338. **Protein Production from Green Leaves.** Pirie, N. W. *World Crops*, 1952, **4**, 374. A mill suitable for recovering the succulent parts of leaves consists of a double

beater, one arm working at a different speed from the other. A 20-h.p. motor drives this machine, which is claimed to produce up to 6 tons per hour of useful ground material. 58 beater arms are carried on the axial shaft, which is enclosed in a drum 4 ft 6 in. long by 3 ft diameter. The mill cannot become choked and has given many hundreds of hours' satisfactory running without damage by stones, etc. The machine is a modified form of the 'Coir Sifter' made by Christie & Norris, Ltd. It is used for routine protein production at the Grassland Research Station, near Stratford on Avon.

2339. **Ball Milling of Pure Ceramic Bodies.** SCHOFIELD, H. Z. *Bull. Amer. ceram. Soc.*, Feb. 1953, **32**, 49–50, 51. Reviews experience in laboratory on ball milling pure ceramic bodies to very fine grain sizes without contamination. Mills lined with Be, C, or rubber, and employing balls of Be, Zr, ZrO_2, MgO and C have been used successfully in various combinations, to mill BeO, ZrO_2, Mg, ZrC, and graphite.

2340. **Fine Grinding of Colours and Chemicals.** STAPLETON, W. A. *Crush. & Grind.*, 1934, **2**, 157–60. Modern methods of pulverizing with air separation are described. The pulverizing of various materials, e.g. colours, chemicals, lime, sugar, coal, gums, pitches, etc., are used in illustration.

2341. **Industrial Minerals.** TAGGART, A. F. *Handbook of Mineral Dressing* (Sect. 3, 1–124). 1945, Wiley & Sons, New York; Chapman & Hall, London. The mechanical treatments of 45 industrial minerals are summarized, to include flowsheets and summaries of the practice at individual mines.

2342. **New Fine Grinding Method.** TRAUFFER, W. E. *Pit & Quarry*, 1950, **43** (2), 58–62. *See* No. 1584.

2343. **Technology and Economics of Ground Mica.** TYLER, P. M. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 889, 1938, 17 pp. General features of the mica industry. Dry grinding and wet grinding. Old and modern methods. Principles of separation. Power consumption. 7 refs.

2344. **Vermiculite.** VARLEY, E. R. (Colonial Geological Surveys, Mineral Resources Division). 1952, H.M. Stationery Office. The methods of winning, preparing and using vermiculite are described. Hammer mills preceded by rolls are briefly mentioned.

Methods of Particle Size and Surface Area Determination

SIZE AND AREA DETERMINATION

2345. **Particle Bank.** Stanford Research Institute, Menlo Park, California (a five-dollar handling fee is charged). Closely-sized particles for calibrating aerosol measuring equipment used in smog studies.

2346. **A Bibliography on Particle Size and Surface Area Determination (with brief abstracts).** Research Council of the British Whiting Federation. Pt I, May 1950, 1–266. Pt II, Dec. 1951, 267–550.

2347. **The Physics of Particle Size Analysis.** *Brit. J. appl. Phys.*, Suppl. No. 3, 1954. Contains the 42 papers and discussion presented at a symposium held by the Institute of Physics at Nottingham, April, 1954. The papers are presented in eight sections: Relative motion of particles and fluids—size separation. Molecular phenomena. Scattering and absorption of light by particles. Particle shape factors. Visual counting and sizing of microscopic particles. Automatized counting and sizing—theory. Photo-electronic machines. General. Summary of conference by H. Heywood.

2348. **Symposium on Particle Size Analysis.** (Institution of Chemical Engineers and Society of the Chemical Industry.) *Trans. Instn chem. Engrs, Lond., Suppl.*, 1947, **25**, 145 pp. Some features of the papers are: The sedimentation fineness of barium sulphate, chromic oxide and pyrolusite, by Andreasen. Critical analysis of methods, by Heywood. Physical factors governing sedimentation, by Davies. The limited application of the heat of wetting method, by Gregg. Electron microscope resolution, by Walton. The need of a planned study for correlating data on pigments and the effect of size in paints, by Newman. The importance of particle size of powders used in the radio industry, by Smith. A new sedimentation apparatus, by Stairmand.

2349. **Bibliography on the Technology of Fine Particles.** O.T.S., U.S. Dept. Commerce, Washington, IR 12827. Copies available from Lending Library Unit, D.S.I.R. 69 references on size or surface determination, for the period 1948–53.

2350. **The Application of Methods of Particle Size and Surface Area Determination of Whiting.** BESSEY, G. E. and SOUL, D. C. *Brit. Whiting Fed. Res. Ass. Tech. Note*, No. 27; *Brit. J. appl. Phys.*, 1954, *Suppl.* No. 3, 181–9. A review of methods available for measuring particle size and surface area. Size is determined directly by wet sieving and sedimentation. Area is measured by methods based on nitrogen adsorption, air permeability, and light absorption of a dilute suspension. It is considered that wet sieving and sedimentation procedures together give adequate and reliable data for the size distribution of whiting.

For the various methods of surface determination, agreement is poor, although the results are of the same order. Internal cracks make the nitrogen adsorption results higher than others, and the process is lengthy. The air permeability method gives a measure of effective surface and is rapid. The optical method results do not show good correlation with those of any other method.

2351. **Micromeritics.** DALLAVALLE, J. M. 1948, Pitman, New York. Chap. 3. Shape and Size Distribution of Particles. Chap. 5. Theory of Sieving and Grading of Materials. Chap. 12. Includes Crystal Growth and Granulation. Dust Explosions. Chap. 16. Determination of Particle Surface. Chap. 17. Muds and Slurries. Physical Properties. Consistency. Coagulation. Settling of Suspensions. Chap. 18. Transport of Particles.

Chap. 19. Dust Clouds. Chap. 20. Atmospheric and Industrial Dust. Chap. 21. Collection and Separation of Particulate matter from Air. Chap. 22. Theory of Fine Grinding. Chap. 23. Sampling.

2352. **Particle Size.** FORSYTH, T. L. *Mfg Chem.*, 1953, **24** (7), 287. The many different methods may be divided conveniently into two classes: those which measure particle size directly, and those which measure primarily the surface area. The former group includes: microscopy, sedimentation, elutriation, centrifuging, X-ray diffraction, light diffraction. The second class includes: adsorption (radioactive indicator, dyes, gas), permeability, heat of wetting, rate of solution, bulk density, tinting effect.

2353. **The Heywood Photoelectric Sedimentometer.** Griffin and Tatlock Catalogue, No. 16 B–S, pp. 14–15. A description, drawing and photo. of the Heywood photo. extinction apparatus on an optical bench $20 \times 2\frac{1}{2}$ in. The surface area of a powder is derived by the given formula from the indicator reading immediately after stirring in the cell (10 cm high); or else a succession of readings as the suspension settles will enable the size distribution of the sample to be calculated.

2354. **Methods of Sizing Analysis.** HEYWOOD, H. *Chemical Engineering Practice*, Vol. 3, Chap. 2, pp. 24–47. Butterworths' Scientific Publications, 1957. Includes methods of surface area determination and the effects of shape factors. 30 refs.

2355. **Science of Fine Powders and its Application.** MAKISHIMA, S. *Kagaku* (*Science*) (in Japanese), 1954, **24**, 452–7; *Chem. Abstr.*, Nov. 1954, **48** (21), 12508. A review of the physical chemistry of fine powders.

2356. **Physics of Particle Size Analysis.** MORGAN, B. B. and BADZIOCH, S. *Brit. Coal Util. Res. Ass. Review*, No. 138, July 1954; *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1954, **18** (7), 301–11. Review of papers presented at a conference convened by the Institute of Physics and held at Nottingham University on 6–9 April 1954. The subject is reviewed under six headings: (1) visual sizing with the microscope; (2) automatized counting and sizing; (3) particle shape factors; (4) scattering of light; (5) relative motion of particles; (6) aggregation and adhesion to solid surfaces.

2357. **A Rapid Method for the Determination of the Specific Surface and Mean Particle Size of Black Powders.** MOTT, R. A. and FRITH, F. *J. Soc. chem. Ind., Lond.*, 1946, **65**, 81–7. The tinting strength test has been standardized so as to obtain complete dispersion of carbon blacks down to 50 micro-mu, the standardization having been done with the electron microscope for the range 300 to 30 micro-mu. The relationship between surface area and mean size for spherical, cubic or slightly prismatic particles is discussed, and this shows the validity of the method in the subsieve range down to 30 micro-mu for black powders. The method has been studied in relation to the fine grinding of coke and coal and should be applicable to white powders if suitable standards can be chosen under the electron microscope. The method is simple, requires little equipment and is very rapid when once learnt.

2358. **Subsieve in Mineral Dressing.** PRYOR, E. J. *Min. Mag., Lond.*, June 1945, **72**, 329–40. Indicates the need for more analytical work and a standardized manipulation. The three main methods of estimating the physical condition of the -200 mesh are described.

2359. **A Comparative Study of the Structure of Porous Glasses by Adsorption Methods and Electron Microscopy.** ZHDANOV, S. P. and GREBENSCHIKOV, I. V. *C.R. Acad. Sci., U.R.S.S.* (*Dokl. Akad. Nauk*), 1952, **82** (2), 281–4. The porous glass is manufactured by a process of leaching alkali borosilicate glass by dilute acid. The resulting character of the porous glass is discussed.

SIZE DETERMINATION

2360. **Symposium on New Methods for Particle Size Determination in the Subsieve Range.** American Society for Testing Materials, 1941, 111 pp.

2361. **Tentative Standard C. 204–46T. Fineness of Portland Cement by Air Permeability Method.** *A.S.T.M. Stand.*, 1949, Pt 3. Diagram and specification of the Blaine apparatus. Formulae and tables for calculation.

2362. **Particle Size Distribution Analyser. The Micromerograph.** ANON. The Sharples Co., Bridgeport, Conn., announces the 'micromerograph' which has been tested for particle size distribution of flour, etc., at ranges of 1–250 microns. The sample of about 0·1 g is de-agglomerated by being blown in a stream of dry nitrogen through a slit into the air sedimentation column. The powder settles on to an automatic torsion balance pan and the weights recorded on a time chart or converted for recording into a weight/density record. The balance arm is maintained in the null position. The probable error is about 3% as compared with a possible error by microscope of 150%. Illustrations, performance data graphs. *Chem. Age, Lond.*, 1955, 26 Feb., 526; *Engineer, Lond.*, 1955, 25 Feb., 283; *Chem. Engng*, Sept. 1953, 250–1; *Food Engng*, Dec. 1953, 71–2, 136–8. *British Chem. Engng*, 1956, **1** (6), 306–11.

2363. **Particle Size of Powders.** ANON. *Chem. Age, Lond.*, 7 July 1956, **75** (1930), 24. Two new instruments by Electroselenium are: (1) the "Eel" powder reflectometer, which is claimed to determine accurately the specific surface of small powders, less than one micron, by the Tinting Strength method, and can be used by unskilled persons; and (2) the "Eel" photoextinction sedimentometer, which enables particles in the subsieve range to be accurately sized.

2364. **Talc and Other Powders.** ANON., *Paint Manuf.*, 1949, **19**, 405. A résumé of the results of the work of Rossi and Baldacci (*Chim. et Industr.*, 1947, **58** (9), 223–7) and of Martin (*ibid.*, 1941, **46**, 590) on size determination.

2365. **Size Distribution of Fine Powders.** *Engineering, Lond.*, 1955, 25 Mar., 378–9. The Micromerograph of Sharples Centrifuges, Ltd., Stroud, Glos., is described and illustrated. A time chart recording the weight of the pan is read by means of a template, to give the weight of particles smaller than a given diameter, after dividing by the square root of the density. If required a template for each density can be provided, in order to avoid calculation.

2366. **Measuring the Particle Size of Powders.** *Lab. Pract.*, 1956, **5** (8), 320 pp. The Eel powder reflectometer is claimed to determine specific surfaces of powders below 1 micron quickly and accurately. (Evans, Electro-Selenium, Ltd.)

2367. **Particle Size and Fine Grinding.** *Sci. Libr. Bibliogr. Ser.*, 1941, (560), 539, 215. A selection of the more theoretical treatments, 1924–41. 40 refs.

2368. **X-Ray Studies of Particle Size in Silica.** ABORN, A. H. and DAVIDSON, R. L. *J. Franklin Inst.*, July 1929, 57–71. Describes apparatus and method for the determination of size of silica particles by X-ray diffraction. Diffraction patterns vary greatly with different samples of the same "average size" when the size distribution varies. Microphotometric studies on the X-ray patterns show a straight-line relationship when certain areas from the microphotometric curves are plotted on log paper against average size if the size distribution is the same. Where size distribution varied, the results were not in accord. Quantitative measurements of size by X-ray diffraction are therefore not yet satisfactory.

2369. **Abrasion of Nine Minerals of Sand Size in Ball Mills.** ALLING, H. L. *Amer. J. Sci.*, 1951, **249**, 569. The results from dry tests show that each mineral has its own peculiarities. The multiplicity of methods for size analysis necessitates better codification and the establishment of conversion factors.

2370. **The Measurement of Particle Size Distribution by Sedimentation Methods.** AMSTEIN, E. H. and SCOTT, B. A. *J. appl. Chem.*, 1951, **1**, Suppl. Issue No. 1, S. 10. Confined to pipette method of sampling a suspension.

2371. **On the Validity of Stokes' Law for Non-Spherical Particles.** ANDREASEN,

A. H. M. *Kolloidzschr.*, 1929, **48** (2), 175–9. Proves Stokes' law theoretically and practically for spherical particles of less than 85 microns diameter, using spherical quartz particles in water. Shows that counting and weighing method to obtain average diameter of particles greater than 5 microns is correct to 1–2%. Separates particles by sedimentation with repeated decantings and determines a constant, use of which Stokes' law applies to ground particles.

2372. **The Results of Some Experiments on the Relation between the Size Distribution of Granulated Materials and the Free Space.** ANDREASEN, A. H. M. and ANDERSON, J. *Kolloidzschr.*, 1930, **50**, 217–28. Data are presented in tabular and graphic form; and expressions are derived for the free space in single, and mixtures of, particle sizes. The significance in grinding is discussed.

2373. **An Apparatus for Particle Size Estimation by the Pipette Method with Special Reference to Industrial Application.** ANDREASEN, A. H. M. and LUNDBERG, J. J. V. *Ber. Dtsch. Keram. Ges.*, 1930, **11**, 249–62; *Kolloidzschr.*, 1929, **49**, 48–51, 253–65. Experimental results are tabulated. These demonstrate the reliability of the apparatus. Examples of its application are presented, e.g. to iron oxide, blanc fixe. 10 refs. (*See also* Andreasen and Berg, 1935, *under* Pigments.)

2374. **Determination of the Particle Size Distribution of Commercial Products in Powder Form by the Pipette Method.** ANDREASEN, A. H. M. *Chim. et Industr.*, 1953, **70**, 863–7.

2375. **A New Method of Expressing Particle Sphericity.** ASCHENBRENNER, B. C. *J. Sediment Petrol.*, 1956, **26** (1), 15–31; *Ceramic Abstr.*, 1956, **39** (11), 250. A method for tridimensional shape analysis is described and an expression derived.

2376. **Grain Size Separation by Means of Centrifuging.** AVY, A. and RAILLIÈRE, R. *Chim. et Industr.*, 1953, **69** (3), 431–4; *Industr. Diam. Rev.*, 1954, **14** (161), 82. *See under* Classification.

2377. **Small Spherical Particles of Exceptionally Uniform Size.** BACKUS, R. C. and WILLIAMS, R. C. *J. appl. Phys.*, 1949, **20** (2), 224–5. A certain polystyrene latex contains particles of a uniform size of 2500 ± 250A in diameter. Their use in electron microscopy is described.

2378. **Review.** BELL, S. H. *Chem. & Ind.* (*Rev.*), 1953, (38), 994. Review of book by H. E. Rose, entitled *The Measurement of Particle Size of Very Fine Powders.* 1953, Constable, London. 9*s.* 0*d.*

2379. **Roller Type Applicator Fineness of Grind Gauge.** BERNSTEIN, I. M. *Industr. Engng Chem.* (*Industr.*), 1950, **42** (5), 908–14. Describes a modified roller type Hegeman gauge block. The Channels 10. in or more long are 0·001 in. at the deepest end and each division represents a change of 2·5 microns. A roller applies the paint or other material, and a scraper knife removes surplus material. The length of ribbon, or better, the onset of scratching denotes the particle size. The theory of this test is discussed, and the importance of particle shape on scratching. The author demonstrates that the test measures the aggregate size rather than the true particle size and that the results depend upon the degree of dispersion in the media. It is demonstrated that with very fine suspensions the particles may form aggregates which are sometimes surprisingly large. The test may be used also for dry powders which, for the test, are dispersed in a liquid. For printing inks, etc., the method only evaluates the oversize range rather than the whole range.

2380. **A Sedimentation Method for the Determination of the Particle Size of Finely Divided Materials.** BISHOP, D. L. *Res. Pap. U.S. Bur. Stand.*, No. 642, Feb. 1934, 11 pp.

2381. **The Blyth Elutriator.** *See under* Pryor, Blyth and Eldridge.

2382. **Some Remarks Concerning Close Packing of Equal Spheres.** BOERDIJK, A. H. *Philips Res. Rep.*, 1952, **7** (4), 303–13. Three criteria are stated for estimating the mean

density of local configurations. Some configurations are described which may have a local mean density exceeding that of close packing. It is proved that the maximum number of spheres simultaneously touching a sphere is twelve. 6 refs.

2383. **Impingement of Particles on Obstacles in a Stream.** BOSANQUET, C. H. *Heat. Vent. Engr*, 1953, **26**, 308–52.

2384. **A Sedimentation Balance for Particle Size Analysis in the Subsieve Range.** BOSTOCK, W. *J. sci. Instrum.*, 1952, **29**, 209. The sample, say half a gram, is dispersed in a suitable liquid and transferred to a sedimentation tube, closed at the bottom by the pan of a torsion balance. A weight–time record enables the size distribution to be calculated. The method is suitable for sizes 2–75 microns. Obtainable from manufacturers.

2385. **A Hydrometer Method for Making Mechanical Analysis of Soils.** BOUYOUCOS, G. S. *Bull. Amer. ceramic Soc.*, 1935, (14), 259.

2386. **Arithmometry. A New Technique in Particle Counting.** BRECH, F. and JONES, A. R. *Analyt. Chem.*, 1955, **27** (2), 319. Abstract of paper to Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, Feb./Mar. 1955. A new instrument is developed for accurate counting to given size ranges. An accuracy of 3% is independent of shape or size, within given limits. A fixed focus microscope is provided with scanning stage, light source, aperture system, photomultiplier and scaling circuits.

2387. **Particle Mechanics.** BROWN, R. L., HAWKSLEY, P. G. W. *Times Review of Science*, Summer, 1954, pp. 6–8. An outline of the field of particle mechanics from electronic counting to fluidized bed phenomena. Illustrations of some of the phenomena are described.

2388. **Particle Size Determination.** CADLE, R. D. Interscience Publishers, Ltd., New York and London, 1955. Interscience Manuals, 295 pp., illustrated. The first three of the ten chapters deal with: (1) significance and applications; (2) treatment of data including distribution functions; (3) sampling methods and choice of technique. The remaining chapters are devoted to: (4) optical microscopy with a brief reference to electronic scanning; (5) electron microscopy; (6) sieve analysis and dimensional calibration; (7) sedimentation and elutriation; (8) surface area measurements (20 pp.); (9) optical methods; (10) miscellaneous methods (pp. 286–297). References after each chapter.

2389. **The Preparation and Assessment of Size-Graded Mineral Samples.** CARTWRIGHT, J. *Min. Fuel and Power, Safety in Mines Estab., Res. Rep.*, No. 128, Aug. 1956, 59 pp., 4*s*. 6*d*. The report discusses methods of preparing samples of minerals and coal of graded size. Particles of greater than 2 microns Stokes diameter are prepared by sedimentation, and the distribution determined by microscope; smaller particles are separated by centrifuging and the distribution determined by electron microscope. Comparison is made between various methods of size distribution. The relationship between various statistical diameters is demonstrated, and a quick method is given for the evaluation of the volume–surface diameter (ND^3/ND^2). This diameter is used for calculating the specific surface of the materials and in comparing projected area diameters with Stokes' diameters. A statistical treatment is given for estimating the error in the calculated value of the volume–surface diameter resulting from random fluctuations in counting. 14 figs, 16 tables, 27 refs.

2390. **Particle Size Distribution from Angular Variation of Intensity of Forward Scattered Light.** CHIN, JIN HAM. *Dissertation Abstr., Ann. Arbor., Mich.*, Publication No. 12 551, 1955, **15** (8), 1361. An integral formula based on modified Bouguer–Beer light transmission equation was used to compute the size distribution of particles, large by comparison with the wavelength of the incident light. Greater accuracy was found by the moving pinhole method and by the microdensitometric method than by

the lens-pinhole method. The possibility of the use of a high-speed measuring and computing system was considered.

2391. **Volume-shape Factor of Particulate Matter. Probable Errors in the Computation.** DALLAVALLE, J. M. and GOLDMAN, F. H. *Industr. Engng Chem.* (*Anal.*), 1939, **11**, 545–6.

2392. **A New Technique for Particle Size Analysis by Centrifugal Sedimentation. The Bahco Separator.** DONOGHUE, J. K. and BOSTOCK, W. *Trans. Instn chem. Engrs, Lond.*, 1955, **33**, 72–7. Existing methods are reviewed and the theory of centrifugal sedimentation is discussed. Previous work has been carried out almost entirely with cylindrical tubes. The present apparatus employs a conical bowl with stepped or terraced side, and mounted on a shaft revolving at 480 or 1500 rev/min. The vertical face of each step is provided with a removable copper strip for deposition of the sediment, drying and weighing (after draining the bowl while still in motion). The advantages of using the variable suspension height method as provided by the steps are discussed. In addition the present method avoids the effects of tangential forces normally observed in deposition on the sides of tubes. The size distribution is calculated from the dry weights of sediment and the dimensions of the bowl and steps. *See also* Avy and Raillère, *under* Classification.

2393. **Particle Size Distribution Analysed Quickly and Accurately.** EADIE, F. S. and PAYNE, R. E. *Iron Age*, 2 Sept. 1954, **174** (1), 99–102. An instrument determines sizes from 1 to 250 microns for use in powder metallurgy, ceramics, abrasives, powder cutting and air pollution control. A cloud of dry particles is introduced at the top of a sedimentation column and falls on to the pan of a sensitive torsion balance.

2394. **Horizontal and Vertical Elutriation.** EDER, T. *Berg.-u.-Hüttenm. Mh.*, 1949, **94** (4), 86. A description is given of methods of horizontal and vertical elutriation of mixtures of various particle sizes, with a formula for calculations for use with the horizontal method. For particle sizes above 0·8 mm a wet screening method is recommended with an accuracy of 95–80% separation, for sizes 0·8–0·2 mm vertical elutriation is advocated as giving an accuracy of separation of 90–75% and horizontal elutriation with an accuracy of 60–40% separation for particle sizes below 0·2 mm.

2395. **Development in the Technique of Particle Sizes Analysis by Microscopical Examination.** FAIRS, G. LOWRIE. *J. R. micr. Soc.*, 1951, **71**, 209–22.

2396. **The Technique of Particle Size Analysis in the Sub-Sieve Range.** FAIRS, G. LOWRIE. Symposium on Mineral Dressing, London, 1952, Paper No. 7. Institution of Mining and Metallurgy. The author has selected four methods for critical review. These are: (1) the graticule methods; (2) sedimentation; (3) air elutriation; (4) specific surface determination (permeability method) as a check on fineness, particularly for pigments. Illustr. Tables of accuracy factors. Published in Recent Developments in Mineral Dressing, 1953, Institution of Mining and Metallurgy. References given are: (1) Fairs, *J. R. micr. Soc.*, 1951, **71**, 209; (2) Fairs, *Chem. & Ind.* (*Rev.*), 1943, **40**, 374; (3) Carey and Stairmand, *Proc. Instn mech. Engrs, Lond.*, 1938, **140**, 314; (4) Stairmand, *Engineering, Lond.*, 1951, **171**, 585; (5) Carman, *J. Soc. chem. Ind., Lond.*, 1938, **57**, 225; (6) Rigden, *J. Soc. chem. Ind., Lond.*, 1943, **62**, 1; (7) Peckover, *Commonw. Engr*, **32**, 211, 1945.

2397. **Average Diameter of Particles just passing the 325-Mesh Sieve.** FRITTS, S. S. *Industr. Engng Chem.* (*Anal.*), 1937, **9**, 180–1.

2398. **Analysis of Particle Size with Hydrometer.** GANDAHL, R. *Geol. Fören. Stockh. Forh.*, 1952, **74** (4), 497–512; *Swedish State Road Inst. Rep.*, No. 22, 1952. A time saving procedure is described which allows say ten determinations a day. Comparison tests with pipette method give reasonable agreement. 8 figs., 8 refs.

2399. **Sizing by Elutriation of Fine Ore Dressing Products.** GAUDIN, A. M., GROH,

J. O. and HENDERSON, H. B. *Industr. Engng Chem.* (*Industr.*), 1930, **22**, 1363–6. Describes sizing by sedimentation and by elutriation. Gives volume of H_2O required for different-size products with three different-size elutriators, also correction factors for temperature and for acetone. Uses 1 g NaOH to 20 litres H_2O and 1 g $CaCl_2$ to 20 litres H_2O for deflocculation.

2400. **Particle Size Analysis of Blast Furnace Slags and Cements, especially in the Range below 10 microns.** GILLE, F. *Zement*, 1942, **31**, 316; *Ceramic Abstr.*, 1944, p. 68. Two dispersing liquids, pyridine and quinoline, were investigated for the pipette analysis of fine-grained materials, e.g. slags, burned lime and slaked lime. For a falling distance of 20 cm, sizes up to 60 microns can be analysed in quinoline and up to 30 microns in pyridine.

2401. **The Determination of the Size of Sub-microscopic Particles by X-rays.** GUINIER, A. *Inform. Circ. U.S. Bur. Min.*, No. 7391, Dec. 1946, 17 pp.

2402. **Studies of the Viscosity and Sedimentation of Suspensions, Pt. 3. The sedimentation of isometric and compact particles.** GUREL, S., WARD, S. G., WHITMORE, R. L. *Brit. J. appl. Phys*, 1955, **6** (3), 83–7. From experiments with cubes of approx. 1 cm. side and with certain other regular-shaped bodies, an expression is derived for the rate of fall in stream line flow in relation to the particle and fluid data.

2403. **Statistical Description of the Size Properties of Non-Uniform Particulate Substances.** HATCH, T. and CHOATE, S. P. *J. Franklin Inst.*, 1929, **207** (3). Describes microscopic count-statistical method for determining average size from frequency curves. Tyndall meter is used to measure surfaces of suspensions. Includes good bibliography. Particle size is defined in terms of the shape and size frequency curves. The size properties are shown theoretically and experimentally to be closely correlated with statistical parameters if the log probability curves and the relationship between size properties and the number of particles per gram and specific surface is given.

2404. **Determination of Average Particle Size from the Screen Analysis of Non-uniform Particulate Substances.** HATCH, T. *J. Franklin Inst.*, 1933, **215**, 27–38. The distribution curve by weight bears a definite relation to the regular size frequency curve, and suitable transformation equations are presented by means of which one is able to calculate *average diameters* from the parameters of the curve given by screen analysis.

2405. **Splitting the Minus 200 with the Superpanner and Infra-sizer.** HAULTAIN, H. E. T. *Trans. Canad. Min. Inst.* (*Inst. Min. Metall.*), 1937, **40**, 229–40. The Haultain infra-sizer consists of seven conical connected air elutriation chambers for separating −200-mesh powder into fractions down to a few microns.

2406. **A New Infra-sizer.** HAULTAIN, H. E. T. *Trans. Canad. Min. Inst.* (*Inst. Min. Metall.*), 1950, **53**, 78–81. This apparatus has only two cones instead of seven, and splits 25 grams of sample into two portions in thirty minutes. An appreciation of results obtained is given by E. J. Pryor *et al.* in *Recent Developments in Mineral Dressing*, pp. 14–15. 1953, Institution of Mining and Metallurgy, London.

2407. **Particle Size Measurement.** HAWKSLEY, P. G. W. *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1944, **8** (9), 245–55. Summary of the recent work on methods of measuring particle size, particularly from 200 B.S. to the finest measurable sizes. The discussion is based on a report of the proceedings of two informal *conferences* in 1941–42, held jointly by the British Colliery Owners Research Association and B.C.U.R.A. Extensive use has been made of the reviews on particle size measurement given by Schweyer and Work and by Martin at a Symposium convened by the American Society for Testing Materials in March 1941. 86 refs.

2408. **Automatic Particle Sizing by Successive Countings.** HAWKSLEY, P. G. W. *Nature, Lond.*, 6 Dec. 1952, **170**, 984–5. The methods and theory for automatic counting and sizing of particles dispersed on microscope slides are outlined. Sizing can be

carried out by recording photo-electrically only the number of pulses totally obscuring the scanning aperture. To obtain the size distribution, the counting is repeated with scanning apertures of different sizes. This recalls the method of automatic counting on microscope slides usually practised, i.e. by measurements of pulse heights or pulse lengths in an area swept by a scanning aperture. The present communication points out that sizing can be done by recording the number only of pulses. The theoretical treatment is outlined. 5 refs.

2409. **The Physics of Particle Size Measurement. Pts. 1, 2 and 3.** HAWKSLEY, P. G. W. *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1951–2. 'Fluid Dynamics and the Stokes' Diameter', 1951, **15** (4), 105–42, 220 refs. 'Optical Methods and Light Scattering', 1952, **16** (4), 117–47; (5), 181–209, 160 refs.

2410. **Fine Particles and Statistics.** HAWKSLEY, P. G. W. *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1953, **17** (11); *Nature, Lond.*, 5 Dec. 1953, 1017–18. Following a general introduction stressing the need for the application of statistical methods to physics, the author reviews a new book on the subject by Herdan and Smith, *Fine Particles and Statistics.*

2411. **The Design and Construction of a Photoelectric Scanning Machine for Sizing Microscopic Particles.** HAWKSLEY, P. G. W., BLACKETT, J. H., MEYER, E. W. and FITZSIMMONS, A. E. *Brit. J. appl. Phys.* 1954, Suppl. 3, S.165–73. Data are presented on the performance of a machine constructed for sizing particles dispersed on microscope slides. The size distribution of a sample of coal particles down to 5 microns as determined by the scanning machine agreed with that from a visual count.

2412. **Fine Particles and Statistics.** HERDAN, G. and SMITH, M. L. 1953, Elsevier Publishing Co., New York and Amsterdam; Cleaver Hume Press, London. 'An Account of Statistical Methods for the Investigation of Finely Divided Materials by Herdan with a Guide to the Experimental Design of Particle Size Determinations by Smith. 520 pp. An appreciation by P. G. W. Hawksley in *Nature, Lond.*, Dec. 1953, 1017–18.

2413. **Numerical Definitions of Particle Size and Shape.** HEYWOOD, H. *Chem. & Ind.* (*Rev.*), 1937, **56**, 149; Paper to Soc. Chem. Ind. (Road & Bldg. Materials Group). A relationship is deduced between the mean projected diameter of a particle and Martin's and Feret's statistical diameters. The particle shapes are divided into four groups: rounded, sub-angular, angular and prismoidal, angular and tetrahedral. The shape coefficients have been determined experimentally for each of these shape groups and are tabulated.

2414. **Measurement of Fineness of Powdered Materials.** HEYWOOD, H. *Proc. Instn mech. Engrs, Lond.*, 1938, **140**, 257–97. Discussion, 308–47; *J. Inst. Fuel*, Dec. 1945, p. 94. A comprehensive review of the methods of size analysis is presented in all aspects and the merits of the various methods are discussed. The motion of irregularly-shaped particles in a fluid and a method of calculating falling velocity in a turbulent fluid are also discussed. 150 refs. are classified under 10 headings.

2415. **A Comparison of Methods of Measuring Microscopic Particles.** HEYWOOD, H. *Bull. Instn Min. Metall., Lond., No.* 477, 1946, 14 pp. The effects of shape on microscope counts and measurements.

2416. **Calculation of Particle Terminal Velocities.** HEYWOOD, H. *J. imp. Coll., chem. Engng Soc.*, 1948, (4), 17.

2417. **Fundamental Principles of Sub-Sieve Particle Measurement.** HEYWOOD, H. Symposium on Mineral Dressing, Lond., Sept. 1952, Paper No. 6. Institution of Mining and Metallurgy. Principles of Particle Motion. Equivalent diameters. Table of free-falling diameters. Similarity groups. Sedimentation methods and theory of sedimentation. Error of hydrometer readings due to bulb length. Repeated decantation.

Elutriation theory. Practical application of decanting test. Hindered settling. 11 refs. Published in *Recent Advances in Mineral Dressing*. 1953, Institution of Mining and Metallurgy, London.

2418. **Centrifugal Sedimentation Method for Particle Size Distribution.** JACOBSEN, A. E. and SULLIVAN, W. F. *Industr. Engng Chem.* (*Anal.*), 1946, **18**, 360–4. A method has been used which is analogous to Oden's method of tangential intercepts for gravitational sedimentation. 12 refs.

2419. **A Comparison of Methods of Particle Size Analysis.** JARRETT, B. A. and HEYWOOD, H. *Brit. J. appl. Phys*, Suppl. No. 3, 1954, S. 21–28. A special test dust was used for comparing the methods and equipment. Recommendations are made by the author for suitable methods of size analysis, with the probable degree of error and the range of size to which the various methods are applicable. The recommendations include those for suspension density, upper size limit, sampling depth in a suspension, method of calculation, dimensions and verticality of apparatus and temperature control. 8 refs.

2420. **Simple Method for Approximate Particle Size Analysis.** JOHNSON, E. I. and KING, J. *Analyst*, Nov. 1951, **76**, 661–2. Sample is shaken in a tube 20 cm long and the liquid above a standard mark removed after a time *t*. The process is repeated until all powder settles below the mark in time *t*. The latter is calculated from Stokes' formula for the required separation.

2421. **Particle Size Analysis and Centrifugal Sedimentation.** JOHNSON, R. *Trans. Brit. Ceram. Soc.*, 1956, **55** (4), 267–85. Centrifugal sedimentation has been found to give differences in the amounts of material sedimented when identical amounts were expected. Experiments have been carried out and various hypothesis examined to explain the deviations from the sedimentation equation. It is thought that the process is affected by coagulation and from impetus from the faster moving particles. Satisfactory size comparisons can be made if the same programme of times and speeds is used, and if concentrations do not vary too much.

2422. **Automatic Particle-sizing by Successive Counting.** JORDANIDES, G. and CHAMBERLAIN, N. H. *Nature, Lond.*, 1954, **174** (4419), 83–4. Some results with automatic apparatus employing measurement of pulse heights or pulse lengths from records obtained from photoelectric scanning devices. Experimental results with 'ideal' specimens consisting of small punched cardboard discs gave good agreements, indicating errors in diameter not larger than 2·5%. 3 illustrations, 1 table.

2423. **A New Sedimentation Apparatus.** KAENDLER, W. and MILLER, L. *Kolloidzschr.*, 1953, **130** (3), 172–6. The cylinder used for sedimentation is provided with a special device for adding the sample, whereby disturbance is avoided by attachment of a manometer tube. The base rests on a brass plate which is fitted with a slider, made watertight by suitable means. The slider has two recesses for small glass plates which receive the deposited powder. The plates can then be removed successively and also replaced by sliding the slide backwards and forwards. The efficiency of separation is illustrated by a curve and by photographs with attached scale. 2 refs.

2424. **How to Understand Problems of Terminal Velocity.** KORN, A. H. *Chem. Engng*, Nov. 1951, 178.

2425. **Methods of Estimating Particle Size.** KUHN, A. *Kolloidzschr.*, 1925, **37**, 365. Determines particle size by: rate of fall by gravity and centrifugal force; the Zsigmondy nucleus method; Oden fractional coagulation method; microscopic counting after centrifuging particles on to one side of a glass cell (different method of counting, and correction to apply); estimation of particle size by light diffraction; determination of particle size by dispersion and osmosis; and counting with the ultramicroscope.

2426. **Magnitude and Character of Errors Produced by the Shape Factors on Stokes' Law Estimates of Particle Radius.** KUNKEL, W. B. *J. appl. Phys*, 1948, **19** (11), 1056–8.

2427. **The Determination of Grain Size.** LEECH, L. G., RATCLIFFE, S. W. and GERMAN, W. L. *Trans Brit. Ceramic Soc.*, 1953, **52** (3), 145–52. A preliminary investigation into rapid testing of fineness by methods unusual in the industry. The new use of the Spekker method and of Rigden's apparatus is compared with the usual hydrometer method, described by N. W. Webb and S. W. Ratcliffe, *ibid.*, 1952, **41**, 51. The Spekker method has been tried on strains and prepared glazes with very promising results. As specific gravity does not enter into the calculations it is possible to determine the surface area of powders containing substances of different specific gravities. A determination can be done in five minutes on a suitable sample. 4 refs.

2428. **Simplified Particle-size Calculations.** LEIGH-DUGMORE, C. H. *Nature, Lond.*, 1954, **174** (4429), 567. When particle sizes are log-normally distributed, tedious summation of powers of the sizes can be avoided if the cumulative distribution is plotted on log-probability paper. From this, estimates of the mean and standard deviations of the distribution of log sizes can be read off, and from these further calculations can be made. Example of method is given.

2429. **Sedimentation Cylinder for Particle Size Analysis.** LEITH, C. J. *Science*, 1951, **113**, 412–3. This has been devised for isolating $\frac{1}{16}$–$\frac{1}{32}$-mm fractions of fine-grain sediments. Features of the Kuhn settling tube and the Atterberg sedimentation cylinder are incorporated in this apparatus.

2430. **Laws of Motion of Particles in a Fluid.** LUNNON, R. G. *Min. & Metall., N.Y.*, 1929, **10**, 333. Abstract of the paper read before Institution of Mining Engineers (England). Gives the three laws (Stokes, Allen and Newton) on falling particles in a liquid.

2431. **Instrumental Particle Size Analysis.** MAJOR, J. R. *Chem. Age, Lond.*, 1955, **72** (1876), 1427–34. An appreciation of modern methods of size analysis, chiefly concerning the size of dusts which affect the lungs. A full discussion is given of the merits and limitations of the various sizing methods.

2432. **Graphic Representation in Size Analysis by Sedimentation Methods.** (In French.) MARTENS, P. H. *Parasitica*, 1949, **5** (4), 110–17. A new graphical method of interpreting Stokes' formula for the settling of suspensions within the size limit of 50–5 microns is described.

2433. **Particle Size. Determination by Sedimentation.** MUELLER, E. E. *Ceramic Age*, 1953, **61** (1), 14–17.

2434. **Automatic Counting and Size Analysis of Microscopic Particles.** NASSENSTEIN, H. *Chem.-Ing.-Tech.*, 1954, **26**, 661; 1955, **27**, 787. Practically no literature in this field exists in Germany. Plenty in U.K. and U.S.A. The new principle is described; designs, action and wiring diagrams of an instrument for automatic evaluation of microphotographs is described.

2435. **Particle Size Analysis from Sedimentation Curves.** NISSAN, A. H. *Disc. Faraday Soc.*, 1951 (11), 15.

2436. **Analysis of Sedimentation.** ODEN, S. *Tekn. Tidskr., Stockh.*, 12 Sept. 1925. Represents sedimentation observations graphically. Weighs suspended plate in the pulp by electrical means.

2437. **A Novel Method for Measuring Particle Sizes of Ceramic Mixtures.** PERKINS, W. W. *Ceramic Ind.*, 1954, **63** (8), 76–7. An adaptation of the knife spread method used in the paint industry.

2438. **The Meaning and Microscopic Measurement of Average Particle Size.** PERROTT, G. ST. J. and KINNEY, S. P. *J. Amer. ceramic Soc.*, 1923, **6** (2), 417–39. Gives formulas for the calculation of 'average' particle size, based on the number of particles, their length, their surface, and their volume. Discusses differences in these various averages.

2439. **Approaches to Aerosol Problems.** PILCHER, J. M. *Battelle Technical Review*, 1956, 5 (4), 3–8. Physical characteristics of aerosols are described and the method of action of the cascade impacter is illustrated and described in terms of terminal velocities of the settling particles.

2440. **Review and Evaluation of Methods of Particle Size Analysis. Pt 1. The Definition of Terms and Classification of Sizing Methods.** PILGRIM, R. F. Research Report No. MD200, Dept. of Mines and Technical Surveys, Mines Branch, Ottawa. April, 1956. 27 pp. This report is the first of a series which will make a complete survey of the published literature and give a critical assessment of available methods.

2441. **Fine Powders and Particles in Industry.** PIRANI, M. and KRAMERS, W. J. *Mon. Bull. Coal Util. Res. Ass.*, 1944, **8** (12), 361–73. A survey of the properties, methods of production, particle size measurement and field of application of powders with special reference to particle sizes employed mainly less than 100 mu. Some eighteen methods of particle-size analysis are tabulated in relation with their appropriate applications.

2442. **Purpose in Fine Sizing, and Comparison of Methods.** PRYOR, E. J., BLYTH, H. N. and ELDRIDGE, A. Symposium on Mineral Dressing, London, Sept. 1952, Paper No. 5., Institution of Mining and Metallurgy. Methods of sizing and sorting. Value of particle size measurement. Description of results from the Haultain infrasizer. Description of modification of the Blyth elutriator and results. Sedimentation methods. Advantages of the beaker elutriation method, and agreement between the three methods are discussed. Published in *Recent Developments in Mineral Dressing*, 1953, Institution of Mining and Metallurgy.

2443. **Rapid Methods of Grain-size Measurement in the Pottery Industry.** RATCLIFFE, S. W. and WEBB, H. W. *Trans. Brit. Ceramic Soc.*, 1942, **41**, 51–70. Two errors which have hampered development of methods are pointed out: (1) concerning velocity of falling particles, and (2) the neglected effects of viscosity changes in the elutriation media. A theoretical discussion concerning these includes the effects of coagulation and dispersion and precedes a critical experimental comparison of pipette and hydrometer methods of determining size distribution using ground flint. 27 refs.

2444. **The Validity of Sedimentation Results.** REID, W. P. *Industr. Engng Chem.* (*Industr.*), 1955, **47**, 1541–44. A mathematical model of a sedimentation experiment for size analysis is considered.

2445. **Practical Determination of Particle Size I.** REUMANN, O. *Glas-Email-Keramo-Technik*, 1954, **5** (5), 186–8; *J. Amer. ceramic Soc.*, 1954 (10), 187. Description of technique, with tables of mesh sizes for D.I.N., U.S. Standard and British I.M.M. sieves. The ideal (Fuller) curve of size distribution for maximum packing density for satisfactory grog is reproduced: 2–4 mm—39%; 1–2 mm—20%; 0·5–1·0 mm—12%; 0·2–0·5 mm—11%; 0·1–0·2 mm—6%; 0–0·1 mm—12%.

2446. **Measurement of Thickness of Fine Particles.** ROBINS, W. H. M. *Nature, Lond.*, 4 Oct. 1952, **170**, 583. A new method of using the projection microscope.

2447. **The Bulking Properties of Microscopic Particles.** ROLLER, P. S. *Industr. Engng Chem.* (*Industr.*), 1930, **22**, 1206. Gives a rapid method of measuring mean particle size.

2448. **Separation and Size Distribution of Microscopic Particles. An Air Analyser for Fine Powders.** ROLLER, P. S. *Tech. Publ. U.S. Bur. Min.*, No. 490, 1931, 46 pp. The separations usually began at 0–5 microns, proceeded in steps of 5–10, 10–20 to 60–100 microns and were calculated from Stokes' law. For soft materials there is an attrition of the grains. The paper indicated corrections for this attrition. A size distribution analysis is made and detailed results of elutriation for a Portland cement and for a chrome yellow pigment are given. Methods of measurement of the fractions and sizes of grains are described.

2449. **Accurate Air Separator for Fine Powders.** ROLLER, P. S. *Industr. Engng Chem.* (*Anal.*), 1931, **3**, 212.

2450. **On the Extinction Coefficient. Particle Size Relationship for Fine Mineral Powders.** ROSE, H. E. and FRENCH, C. C. J. *J. Soc. chem. Ind., Lond.*, 1948, **67** (7), 283–9. An account is given of the researches which have led to an experimentally derived curve relating the extinction coefficient to the particle size in the range 0–50 microns. While the validity is not rigidly established, the curve is believed to be more reliable than those previously suggested, and sufficiently accurate for many industrial purposes.

2451. **Powder Measurement by a Combination of the Methods of Nephelometry and Photo-Extinction.** ROSE, H. E. *J. Soc. chem. Ind., Lond.*, 1950, **69** (9), 266–72. The combined technique could be a more convenient and accurate method of powder size analysis than the photo-extinction method. Certain relationships have been derived and are shown to be in agreement with experiment. From the results of scattered light tests, the extinction coefficient/particle size relationship has been computed, and reproduces in detail a significant feature of the curve as determined by direct measurement. More detailed investigation is planned.

2452. **The Design and Use of Photo-Extinction Sedimentometers.** ROSE, H. E. *Engineering, Lond.*, 1950, **169**, 31 Mar., 350–1, 14 April, 405–8. A full treatment of the subject with graphical representation of data is presented. 11 refs.

2453. **The Measurement of the Particle Size of Very Fine Powders.** ROSE, H. E. Four Lectures, Nov. 1951, at King's College, London. Theoretical and practical aspects. He concluded that the techniques necessary for examining the properties of flocs and the voidage function and streaming effects in permeability measurements were amongst those subjects which still need investigation. A summary is given in the Bulletin of Whiting Federation Research Council, Mar. 1952. Published in book form by Constable, 1953. Review by S. H. Bell in *Chem. & Ind.* (*Rev.*), 1953 (38), 994.

2454. **The Assessment of Specific Surface by Single Observation Photo-Extinction Methods.** ROSE, H. E. *J. appl. Chem.*, 1952, **2** (4), 217–20. The method by total extinction of a suspension is subject to considerable error. Thus the convenient method based on a single measurement of opacity is unsatisfactory even for moderate accuracy, and recourse must be had to deriving a size frequency curve. In the present paper empirical expressions are derived whereby a value of specific surface in close agreement with that obtained from a size frequency analysis may be obtained from a single measurement of a suspension of a powder.

2455. **The Permeability Method of Specific Surface Determination. A Correction Factor.** ROSE, H. E. *J. appl. Chem.*, 1952, **2** (9), 511–20. The application of the Carman equation is found to depend on the porosity of the bed. In this paper a correction is developed which largely eliminates this variation. Further, for those powders which have been analysed by alternative techniques, the values of specific surface as determined by the 'corrected' Carman's equation show deviations from the values obtained from photo-extinction and nitrogen adsorption techniques which would have been predicted from known limitations of the methods.

2456. **New Practical Method of Studying Particles.** ROSE, H. E. *Chem. Prod.*, 1955, **18** (10), 375–7. A method is given and simple apparatus described for the estimation of diameter, thickness and aggregation properties of non-spherical particles of magnetically anisotropic materials. Using the photo-extinction method, the projected areas of the particles can be determined both at random orientation and when aligned by an applied magnetic field. In view of the theoretical assumptions made and of the restriction of the method to approximately circular discs or cylindrical rods of magnetically anisotropic materials, it is clear that the method is unlikely to be highly accurate or of universal use. Nevertheless, it offers a fairly simple method for obtaining useful qualitative information. These possibilities are itemized for the various effects of the

magnetic field on the amount of light extinction. It is suggested that the present method could be usefully employed in conjunction with the microscope or electron microscope, and that the degree of aggregation can be assessed merely by determining the ratio of the logs of the two light extinction values.

2457. **Determination of the Particle Size of Fine Powders with Particular Reference to Kaolins.** ROSSI, C. and BALDACCI. *J. appl. Chem.*, 1951, **1** (10), 446–52. A sedimentation method using one arm of a hydrostatic balance is described.

2458. **An Exact Method for Determining a Shape Value for Particles.** SCHULZ, F. *TonindustrZtg*, 1954, **78** (15/16), 231–4. A granulometric analysis of a powdered mineral is not complete without including a value for the shape of the grains. After examining the known methods, the author develops an expression of the form: $nKe = Zl^2b - 100$ (Z = no. of grains, l = length, b = breadth). Examples of application of the formula are given.

2459. **Sedimentation as a means of Classifying Extremely Fine Clay Particles.** SCHURECHT, H. G. *J. Amer. ceramic Soc.*, 1921, **4**, 812. Describes plummet sedimentation method, classifying particles as small as 0·0001 mm. Describes Sven Oden method of weighing sedimentation on a suspended plate. Weigener's apparatus is described, using two connected tubes, one large one containing the material and one small one containing condensed water. When connected the heavier material (in larger tube) raises water in smaller tube. The Bureau of Mines apparatus consists of a suspended plummet, the weight of which indicates the density of the pulp.

2460. **Particle Size Determination in the Sub-Sieve Range. Methods.** SCHWEYER, H. E. and WORK, L. T. *Industr. Engng Chem. (Anal.)*, 1942, **14** (8), 622–3; *Chem. Rev.*, 1942, **31**, 295–317. The hydrometer, pipette and Wagner turbidimeter methods for determining particle size distribution in the sub-sieve ranges were studied in detail. The results on a variety of ground materials indicated that the hydrometer and pipette methods give concordant data, in agreement with those obtained by air elutriation. On the basis of these results a special pipette for rapid analysis was designed. The reasons for unsatisfactory data by the Wagner turbidimeter (except for a limited number of materials) are discussed.

2461. **Application of Particle Size Measurement to Pulverized Fuel.** SKINNER, D. G. Pulverized Fuel Conference, 1947, pp. 519–25. Institute of Fuel. Review of methods and consideration of advantages and disadvantages of these. The sedimentation method appears to be the most suitable method. From point of view of the fuel technologist the specific surface measurement gives a more satisfactory indication of fineness than size distribution. For rapid routine analysis, the turbidity and permeability methods are both suitable.

2462. **Methods of the Estimation of Size Distribution of Dusts from Size Measurements and Rate of Fall.** SMEKAL, A. 1936, Verein Deutsche Ingenieur Verlag, Berlin. (Committee on Dust Technique.)

2463. **Determination of Particle Size Distribution by Sedimentation Method.** SMITH, J. S. and GARDENIER, R. Jr. *Analyt. Chem.*, 1953, **25** (4), 577–81. The sedimentation tube is provided with a side arm for containing an immiscible liquid to balance the weight of powder and liquid medium in the sedimentation tube. The height of the balancing liquid in the side arm is a measure of the decreasing weight in the sedimentation tube and therefore of the weight of powder settled. The change in weight with time is recorded and from this and other data the size distribution is calculated. 13 refs. Mathematical relations and curves are presented.

2464. **Size Testing.** TAGGART, A. F. *Handbook of Mineral Dressing*, 1950, Wiley & Sons, New York; Chapman & Hall, London. Sect. 19, pp. 100–45. Methods and presentation of sizing tests.

2465. **Particle Size Analysis of Powders and Dusts by Nephelometric Procedure.** TELLE, OTTO VON. *TonindustrZtg*, 1952, **76** (23/24), 369–72. A description, with graphical presentation of experimental data of the 'photo-electric sedimentometer'. 11 refs.

2466. **The Measurement of the Shapes of Rock Particles.** TESTER, A. C. *J. Sediment. Petrol.*, 1931, **1**, 3–11.

2467. **Particle Size Measurement of Kaolin and other Clay Materials.** VINTHER, E. H. and LASSON, M. L. *Ber. Dtsch. keram. Ges.*, 1933, **14**, 259–79. (1) Experimental work indicated that the Andreasen pipette is the best sedimentation apparatus to use, and is most suitable for sizes from 0·5 to 20 microns. (2) Kohn's assumption that the sample withdrawn is from a spherical volume of the liquid is not supported. (3) Manipulation, and type of peptizer are important. (4) Sodium pyrophosphate was found to be the best peptizer. (5) A new apparatus which will measure at 0·13–0·5 microns in the course of four days is described. (6) By this means various kaolins can be identified.

2468. **Shape of Rock Particles.** WADELL, H. *J. Geol.*, 1932, **40**, 443–51; 1933, **41**, 310–31; *Pan. Amer. Geol.*, 1934, **61**, 187–220. (1) Volume, Shape and Roundness of Rock Particles. (2) Sphericity and Roundness of Rock Particles. (3) Shape and Determinations of Large Sedimentary Rock Fragments.

2469. **Grindometer.** WALKER, W. C. and ZETTELMOYER, A. C. *Amer. Ink. Mkr.*, 1949, **27** (9), 67–9; 1950, **28** (7), 31–4. A fineness of grind gauge for printing inks is of the drawn-down type, using a groove with a maximum depth of 0·001 in. A wider groove than normal allows greater accuracy.

2470. **Assessment of Particle Size. Determination of Two Profile Parameters for Irregular Shapes.** WATSON, H. H. and CRUISE, A. J. *Engineering, Lond.*, 1954, **177** (4606), 594–6. Results of experimental work on direct measurement from magnified profiles by photoelectric means are discussed for a variety of dusts examined.

2471. **Dense Random Packing of Unequal Spheres.** WISE, M. E. *Philips Res. Rep.*, 1952, **7** (5), 321–43. Dense random packing is defined in a new way in terms of a probability distribution function for tetrahedra. 9 refs. *See also under* Boerdijk.

2472. **Sedimentation of Powders in Liquids.** WOLF, K. L. *Dtsch. Farberztg*, 1955, **9**, 377–87; *Chem. Age*, 29 Oct. 1955, 955–7. Results of some recent German work show that among the governing factors, besides density and viscosity of the medium, on the rate of settling and volume of sediment, are the forces between the particles and between these and the medium. A large number of liquids and the chemical and physical properties of some solids have been correlated with apparent anomalies in sedimentation. The extent of aggregation during sedimentation is described for ten varieties of silica gel and kieselguhr. Aggregation from 0·1 micron to 70 microns is typical. The effects of temperature, surface active agents, quantity of solid, pH and polarity of the materials were also studied. 6 refs., from 1941–54, are given.

2473. **The Graphical Analysis of Fineness Distribution Curves of Pulverized Materials.** WORK, L. T. *Proc. Amer. Soc. Test. Mater.*, 1928, **28**, 11. Reviews various methods of measuring particle size of fine material. Favours 'direct' method of microscopic measurement involving statistical analysis.

2474. **Crushing and Grinding.** WORK, L. T. *Industr. Engng Chem.* (*Industr.*), 1947, **39**, 11. The extension of particle-size measurement has led to more exact product control, and just before the war standardization of sieves was effected in the American Standards Association. Procedures for sieving and the testing of sieve performance, are not yet fully standardized. The electron microscope has opened new vistas for photographic examination in the sub-sieve range, and sedimentation methods have been checked with other methods, and the usefulness of the hydrometer. Andreasen pipette and Wagner turbidimeter has been defined. Centrifugal sedimentation, the

air analyzer, spectral transmission studies, gas permeability methods and gas adsorption for total surface are techniques of widening application and extensive work has been performed on the correlation of shape factors.

2475. **Crushing and Grinding. Size Reduction.** WORK, L. T. *Industr. Engng Chem.* (*Industr.*). This is one of the Unit Operations section of each January issue of *Industr. Engng Chem.* (*Industr.*), from 1947, **39** to 1953, **45**; in later years, in the March issues. A summary of published papers on particle size measurement is included.

2476. **Particle Size Determination by Soft X-Ray Scattering.** YUDOWITCH, K. L. *J. appl. Phys.*, 1949, **20** (2), 178–82.

2477. **The Preparation and Particle Size Measurement of Mono-disperse Gold Colloids.** ZILVERSMIT, D. B., BOYD, G. A. and BRUCER, M. *J. Lab. clin. Med.*, 1952, **40**, 261–6; *Chem. Abstr.*, 1954, **48** (19), 11150.

SURFACE AREA DETERMINATION

2478. **Tentative Standard C.115 Determination of the Specific Surface of Fine Powders by the Turbidity Method.** *A.S.T.M. Stand.*, 1949, Pt 3.

2479. **The Modified Rigden Air-Permeability Method for Determining Specific Surface of Powders as used at the Fuel Research Station.** *Fuel Res. Bd. Pap.*, No. 198, Jan. 1956.

2480. **The Physics and Chemistry of Surfaces.** ADAM, N. K. 1941, Oxford Univ. Press, London (3rd Ed.); Clarendon Press, New York.

2481. **Permeability Studies.** ARNELL, J. C. *Canad. J. Res.*, 1949, A27, 207–12. IV. Surface area measurements of zinc oxide and potassium chloride powders. 10 refs. The use of the modified Kozeny equation for measurement of specific surfaces of fine powders has been extended to include a number of standard zinc oxides and a sample of potassium chloride. The specific surfaces have been measured by ten other methods and the data tabulated for comparison. Satisfactory agreement with other methods was found. Apparatus and technique of the method (air permeability at five different mean pressures) is summarized.

2482. **Some Theoretical Questions on Dust Technology.** (In Hungarian.) BEKE, B. *Magyar Energia* (*Hungarian Power Economy*), 1953, **6** (9), 259–67; *Hungarian Technical Abstracts*, 1954, **6** (3), 79. Deals with the Kolmogorov.–Renyi theory of grain structure based on probability calculus; is unequivocal and determines specific surface by the formula: $S=(6/ay)e-(5b^2/2)$ where a and b are constants.

2483. **The Determination and Practical Value of Specific Surface.** BORNER, H. *TonindustrZtg*, 1954, **78** (13/14), 204; *Montan. Rdsch.*, 1954, **2** (10), 263. An examination is made of the various methods of specific surface determination. There are several methods for determining 'practical' values, but the gas adsorption method for determining the 'true' value, including internal cracks has not yet sufficient experimental evidence to judge its reliability. Therefore one must generally be content with the relative values such as those obtained by the permeability methods of Lea and Nurse, Blaine and Pechukas. The optical procedures are less exact and more difficult to apply. Mathematical and graphical methods are also used. All these methods are examined with their advantages and disadvantages in relation to practical applications, and numerical relations between results.

2484. **Grinding Theory.** BUDNIKOFF, P. P. and NERKRITSCH, M. I. *Zement*, 1929, **18**, 194–8, 230–3. Discusses *inter alia* Kochler's method of ThO adsorption for surface measurement.

2485. **Determination of Surface Area of Powders by Means of Low Temperature Adsorption Isotherms.** BUGGE, P. E. and KERLOGNE, R. H. *J. Soc. chem. Ind., Lond.*, 1947, **66** (11), 377–81.

2486. **Size and Surface of Powders.** CARMAN, P. C. *J. Chem. Soc. S. Afr.*, 1939, **39**, 266–81. General account of the significance of the term 'particle size' and of the methods of measurement. Brief survey of methods for surface area measurement and an account of results of experiments by the permeability method. 9 tables of results. 27 refs. Discussion by V. L. Bosazza. *Ibid.*, Sept. 1939, **40**, 142–5. 12 refs.

2487. **Surface Area Measurements of Fine Powders using Modified Permeability Equations.** CARMAN, P. C. and ARNELL, J. C. *Canad. J. Res.*, 1948, **26A** (3), 128–36. The author has shown that for glass beads and irregular surfaces, the permeability method does not measure microscopic pores, irregularities and cracks. Adsorption accounts for these.

2487. **Physical Adsorption of Gases on Porous Solids.** CARMAN, P. C. and RAAL, F. A. *Proc. roy. Soc. A.*, 1951, **209**, 38–58, 59–69, 69–81. Pt. I. Comparison of loose powders and porous plugs. Pt. II. Calculation of pore size distributions. Pt. III. Surface diffusion coefficients and activation energies.

2489. **Analysis of the Area Determinations of Copper Powders.** CUMING, B. D. and SCHULMAN, J. H. Symposium on Mineral Dressing, Sept. 1952, Paper No. 4. Institution of Mining and Metallurgy. 100–200-mesh copper particles ((spherical) were used. (A) Krypton Adsorption. (B) Geometrical Area. Microscope (by G. L. Fairs). (C) Stearic Acid Adsorption from Petrol Ether 80°–100°C. (D) Sodium Dodecyl Sulphate (S.D.S.) Adsorption from Aqueous Solution. The areas (c.c./g) ranged from 63 to 90 (Krypton highest). The methods were applied after heating to 360°C in oxygen for 2 hours. The krypton and stearic acid methods gave 610 and 400 c.c./g respectively. The S.D.S. and microscope methods gave 90 and 70. Thus the 'true area' is 7–9 times the 'geometrical area'. 5 refs. Published in *Recent Developments in Mineral Dressing*. 1953, Institution of Mining and Metallurgy.

2490. **Calculation of the Specific Inner Surface of a Porous Body.** DAHME, E. *Ingen.-Arch.*, 1953, **21** (5–6), 346–51. Based on known techniques of measurement.

2491. **Research on Surface Properties of Fine Particles.** DALLAVALLE, J. M., CLYDE, O. and BLOCKER, H. G. Georgia Inst. of Technology, State Engineering Experimental Station Project, Mar. 1951, PB104372, 143–68. Obtainable in microfilm or photostat form from: Lending Library Unit, D.S.I.R. Price 18*s.* 3*d.*, enlarged prints 73*s.* 0*d.* Deals primarily with studies of methods. Method based on adsorption of fatty acids is promising. Diagrams, graphs, comprehensive bibliography, discussion, 73 pp.

2492. **Research on Surface Properties of Fine Particles.** DALLAVALLE, J. M., ORR, C. Jnr. and BLOCKER, H. G. *Georgia Inst. Technology, Engineering Experimental Station Quarterly Reports*, Nos. 2, 3, 4, 5, 7 and Final. 30 April 1951 to 30 April 1952. See also *Nuclear Sci. Abstr.*, **8** (21), 773, 808, 845, Nov.–Dec. 1954, also 15 Jan. 1955, p. 9.

No. 2. Both gas and fatty acid adsorption methods are found to be applicable to surface area measurement, but the former was limited to materials having a large surface area and the latter by unwieldy titrations.

No. 3. Two variations of the usual low-temperature gas adsorption technique were studied. The rate of adsorption method is described in detail and a few results are given. The results of the continuous flow method are presented and discussed.

No. 4. Surface area was determined by liquid phase adsorption of stearic acid and by gas adsorption methods. Agreement was good for surface areas less than 50 m^2/g. Above this, small fissures played a more important part. The characteristics of nickel powders were determined as above.

No. 5. A comparison is made between gas adsorption on to metal powders and on to metal films. The latter far exceed powders in catalytic activity.

No. 7. The results of chemisorption of hydrogen gas, at the temperature of liquid nitrogen, on to nickel powder are described. Somewhat more heat is liberated than for nitrogen under the same conditions.

Final Report. In addition to the study of methods of surface area determination, the adsorption of dyes, iodine and fatty acids from liquid solutions at room temperature were investigated. The usual methods for particle size measurement were also evaluated.

2493. **Standardization of Surface Properties of Fine Particles.** DALLAVALLE, J. M., ORR, C. Jnr. and BLOCKER, H. G. *Georgia Inst. Technology Engineering Experimental Station, Quarterly Reports*, Nos. 1 and 3, 30 July 1953, 30 Jan. 1954. See also *Nuclear Science Abstr.*, 30 Oct. 1954, **8** (20), 748.

No. 1. A number of measurements were made by means of a suitably devised instrument on the heat adsorption of a gas by powders. These all indicated that the heat developed up to the formation of a monomolecular layer was equivalent to heat of liquefaction of the gas at the operating temperature.

No. 3. Refinements in apparatus and techniques are described for purification of nitrogen and helium gases, pressure measurement and sample preparation. Preliminary data are included for the adsorption of gas on charcoal.

2494. **The Mining and Dressing of Low Grade Ores in Europe.** DAVIES, W. *O.E.E.C. Technical Assistance Mission*, No. 127, 1953. 1955, O.E.E.C., Paris. Obtainable from H.M. Stationery Office. In discussion of the paper by J. Murkes, Institute of Mineral Dressing, Stockholm, Dr W. Davies of U.K. said that he measured the size of a large number of ammonium nitrate crystals (rhombic prisms) and then calculated the surface area. Then the specific surface was calculated by the permeability method. It was concluded from the close correlation for samples down to 250 mesh that the shape factor had little effect on the surface area determination. Mr J. Svensson said that, in their experience, the shape factor did not vary much for near isometric particles, but for needle-shaped or lamellar particles, the shape factor reached a value of 7–8 as against the usual 5.

2495. **Specific Surface of Magnetite.** DAVIS, C. W., DEAN, R. S. and GOTTSCHALK, V. H. *See under* Magnetic Effects.

2496. **The Use of the Coercimeter in Grinding Tests.** DE VANEY, F. D. COGHILL, W. H. *Trans. Amer. Inst. Min. Engrs*, 1939, **134**, 283–95. The relations between the coercive force of magnetite and surface area of a sieved fraction were investigated. *See under* Magnetic Effects.

2497. **Calibration of Air Permeability Particle Sizes.** DUBROV, B. *Analyt. Chem.*, 1953, **25** (8), 1242–4. The method of calibration employs two fritted glass diffusion tubes as standards, calibration being made by two different procedures. 4 refs.

2498. **Determination of Specific Surface of Sieve Size Powders.** DUBROV, B. and NIERADKA, M. *Analyt. Chem.*, 1955, **27** (2), 302–5. An instrument adaptable to rapid routine measurement is described. The range of air permeability measurements is extended to sieve size powders, and an instrument which employs a sensitive adjustable flow meter was developed. The accuracy obtained indicates that the instrument can be adapted for routine size or surface measurement within the range investigated, i.e. 16–250 mesh (or 1000–57 microns).

2499. **A Direct Comparison of Silvering and Permeability Methods of Determining Specific External Surface.** EMERTON, H. W., MATTOCKS, R. E. and BLANCHARD, D. M. W. *Paper Tr. J.*, 1954, **37** (2), 55–6. The results by the permeability method after the beaten pulp had been silvered agreed with those by the silvering method after the pulp had been silvered, these being $0{\cdot}86 \pm 1{\cdot}6\%$ and $0{\cdot}63 \pm 18\%$ sq. m/g respectively, but were much less than those by the permeability method (unsilvered) which were $5{\cdot}42$–$6{\cdot}40 \pm 13\%$ and $\pm 3\%$ sq. m/g respectively. Results from another pulp were similar. It is therefore concluded that the silvering operation, *per se*, reduces the external surface of the beaten fibres very considerably. The T.A.P.P.I. silvering T.266 s.m.46 method and permeability method were used.

2500. **Meeting of the Deutschen Keramischen Gesellschaft in Baden. Sept. 1953.**

Determination of Specific Surface by Air Permeability. Engelhorn, P. *Sprechsaal.*, Oct. 1953, **86** (20), 507. The importance of considering the porous nature of a material in such measurements is pointed out in a contribution.

2501. **Determination of Geometric Surface Area of Crushed Porous Solids.** Ergun, S. *Analyt. Chem.*, 1952, **24**, 388–93. A useful method of measuring surface areas is described. It is a gas flow method depending on the relation between pressure drop and the flow rate and bulk density. 86 refs. (A geometric surface may be visualized as that of an impervious envelope surrounding the body in a geometric sense (irregularities and striae being neglected).)

2502. **Surface Area and Amount of Heat in Crystallized Magnesium Hydroxide.** Fricke, R., Schnabel, R. and Beck, K. *Z. Elektrochem.*, 1936, **42** (12), 881–9. A translation may be consulted at D.S.I.R. Ref., Records Section, 4776.

2503. **Surface Measurement by Van der Waals Adsorption.** Gaudin, A. M. and Bowdish, F. W. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 95–102; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1666, 1944. Details of method by adsorption of liquid nitrogen. The area per adsorbed molecule of nitrogen is considered to be Emmett and Brunauer's value of $13{\cdot}8\ A^2$.

2504. **Crushing and Grinding. I, II and III.** Gross, J. and Zimmerley, S. R. *Trans. Amer. Inst. min. (metall.) Engrs*, 1930, **87**, 7, 27, 35. Surface measurements of quartz. *See under* Fundamental Aspects.

2505. **Crushing and Grinding. 1. Surface Measurement of Quartz Particles.** Gross, J. and Zimmerley, S. R. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 46, 1928; *Milling Methods*, 1930, 7. The hydrofluoric acid solution method and extrapolation to zero rate are described. This initial rate is a true measure of surface. Calibration of these initial rate values for the conversion to definite surface units was done by silver coating of quartz. The accuracy of the method is discussed. *See also under* Gross, 1928. (Gross regards the results as definitely establishing the Rittinger theory.)

2506. **A Method for the Sizing of Ore by Elutriation.** Gross, J., Zimmerley, S. R. and Probert, A. *Rep. Invest. U.S. Bur. Min.*, No. 2951, 1929, 8 pp. Determines sizes of mineral particles obtained in elutriation products from −200-mesh ore by comparison with quartz particles obtained under identical conditions of elutriation. Surface figures for galena, sphalerite and pyrite are given for sieve sizes and elutriation products.

2507. **Wetting of Pigments and Other Powders.** Harkins, W. D. and Dahlstrom, D. A. *Industr. Engng Chem. (Industr.)*, 1930, **22**, 897. Determines the heat of wetting or energy of immersion and describes the calorimeter and method of operation.

2508. **Surface Area Determination.** Harkins, W. D. and Jura, G. *J. Amer. chem. Soc.*, 1944, **66**, 1362–6, 1367–73. An absolute method for determining the area of a finely-divided crystalline solid. A vapour absorption method without the assumption of a molecular area, and the areas occupied by nitrogen and other molecules on the surface of a solid.

2509. **Calculation of the Specific Surface of a Powder.** Heywood, H. *Proc. Instn mech. Engrs, Lond.*, 1933, **125**, 383. The specific surface can be calculated from a knowledge of three factors, namely, the density, the shape coefficient and the surface mean diameter of the particles. The method of determining shape coefficients is described, together with values for typical materials. The chief difficulty is the accurate determination of surface mean diameter for the particles. This quantity is defined mathematically and a graphical method is given for the direct calculation of the surface mean diameter from the residue curve plotted to Rosin's functional scales, i.e. $\log \log 100/R$ against $\log x$.

2510. **Grain Size Measurement and Permeability of Foundry Sands.** Jasson, P. *Fonderie*, 1952 (73), 2795–2804. Tabulated data and graphs are given, and practical

applications of theory are considered. Allowances must be made for density of packing in correlating theoretical and actual permeability.

2511. **Absorption and Adsorption of Bases by Solids.** JONES, C. P. *Soil Sci.*, 1924, **17**, 255–73. Obtains adsorption of $Ca(OH)_2$ on quartz, giving titratable values for quartz sizes of 40–60 mesh, 60–80 mesh, 150–200 mesh and −200 mesh. Results are somewhat erratic, although some show a fair proportion to theoretical surfaces.

2512. **Determination of Specific Surface of Barium Sulphate, Comparison of Results by Different Methods.** JOPLING, E. W. *J. appl. Chem.*, 1952, **2** (11), 642–51. A description is given of the pipette and centrifuge methods of determining grain size distributions by sedimentation, and results are given for a number of barium sulphate powders. From the size distribution curves, the specific surfaces are calculated and compared with values obtained by air permeability, dye adsorption and light extinction method. The results from the air permeability and dye adsorption methods are in good agreement with each other, but not always with the sedimentation results. The failure of the optical method is attributed to fineness of the powders.

2513. **A Simple Method for the Determination of the Free Surfaces in Finely Ground Solids.** (In German.) KARAGOUNIS, G. *Helv. chim. acta*, 1953, **36**, 282–90; *Öst. ChemZtg*, 1954, **55** (5/6), 79–80. The method is based on coating the particles with an organic liquid (from an ether solution, if necessary) and assuming that an excess of coating over a critical value is denoted by a waxy property causing the particles to adhere. Surface area is calculated from the weight of coating as compared with that on a known area.

2514. **Evaluation Problems in Fine Grinding.** KIESSKALT, S. (Aachen). *Chem.-Ing.-Tech.*, 1954, **26** (1), 14–17. The attainment of a specific surface area of quartz by means of a vibrating ball mill was investigated. Calculation of surface from the results of normal sieve analysis was done and the results compared with those of the argon adsorption method of Blaine. Answers to some evaluation problems were obtained.

2515. **Relation between Fineness of Limestone and its Rate of Solution.** KREIGE, H. F. *Rock. Prod.*, 1926, **24**, 65–8. Gives a method of surface determination for calcite and limestone based on the dissolution rate in hydrochloric acid.

2516. **The Determination of the Surface Area of Fine Powders.** LANDT, E. *Kolloidzschr.*, 1954, **135** (2), 91–6. An absolute method is put forward for the determination of the surface area of non-porous powders based on theoretical considerations of the heat developed when immersed in an indifferent liquid. Previous work is reviewed. 19 refs.

2517. **Harkins–Jura's Entropy Method for Determination of Specific Surfaces of Powders.** LANDT, E. *Kolloidzschr.*, 1954, **139** (3), 170–1.

2518. **The Specific Surface of Fine Powders.** LEA, F. M. and NURSE, R. W. *J. Soc. chem. Ind., Lond.*, 1939, **58**, T277–83. Modified by Carman for determining specific surface of cement. *See under* Cement.

2519. **Surface Energies of Solid Oxides and Carbides.** LIVEY, D. T. and MURRAY, P. *J. Amer. Chem. Soc.*, 1956, **39** (11), 363–72. The surface energies of the alkali halides are considered in relation to various parameters such as lattice energy molar volume, and heat of formation and solution. The values calculated on these bases are tabulated for the four types of halide. The conclusions derived are applied to a consideration of the surface energies of the oxides which range in value from 250 for PbO to more than 1420 ergs/sq. cm for BeO. The surface energies of the oxides are compared with those of refractory monocarbides as determined by wetting experiments. The surface energies of these ranged from 800 ergs/sq. cm for ZrC to 1675 for VC, and show a linear relationship with heat of formation. 7 tables, 20 curves, 23 refs.

2520. **Assessment of Specific Surface of Powders and Porous Solids by Adsorption**

Methods. Maggs, F. A. P. *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1945, **9** (9), 253–61. 15 refs.

2521. **A New Surface Measurement Tool for Mineral Engineers.** Mortsell, S. and Svensson, J. *Min. Engng, N.Y.*, 1951 (11), 981–3; *Trans. Amer. Inst. min. (metall.) Engrs*, 1951, **190**, 981. This paper by F. W. Bloecher is discussed by Mortsell and Svensson, who throw doubt on the suitability of the gas adsorption method for mineral dressing laboratories, owing to different and higher results as compared with surface calculated from particle dimensions. Other reasons are given. A curve is given showing the specific surface of quartz ground in a ball mill as a function of the net energy input to the mill.

2522. **The Use of the Microscope for Accurate Measurement of the Surface of Small Particles.** Pidgeon, F. D. and Dodd, C. *Peint-Pigm.-Vern.*, 1953, **29** (10), 312–17. A modified projection method is described wherein the surface is projected on to a reticule-objective. By this method it is unnecessary to assume a shape factor, which is claimed as the chief advantage. Very small dimensions can be measured, and results with finely-divided quartz are compared with those by less direct methods and presented in tabular form. There is reasonable agreement. The limits and possibilities of application are discussed. 14 refs.

2523. **Permeability Method of Specific Surface Determination.** Rose, H. E. *J. appl. Chem.*, 1952, **2** (9), 511–20.

2524. **Adsorption.** Schmidt, G. C. and Durau, F. *Z. phys. Chem.*, 1924, **108**, 128–50; *Chem. Abstr.*, 1924, **18**, 1598. Obtains adsorption of aniline dyes on powdered glass and glass plates to determine whether there is a monomolecular layer. Surface of powdered glass determined by method of Wolff (*Chem. Abstr.*, 1922, **16**, p. 2017). Methyl violet and diamond fuchsin used. Layer determined to be 2 molecules thick, assuming cubical molecules. (As Wolff's method gives low results, the adsorbed layer may be only 1 molecule thick.)

2525. **Principles of Comminution.** Schumann, R. *Tech. Publ. Amer. Inst. Min. Engrs*, No. 1189, 1940, 10 pp. I. Size Distribution and Surface Calculations. *See under* Jaw Crushers.

2526. **A Study of Adsorption as a Method for the Determination of the Surface of Pulverized Coal.** Sherman, R. A. *et al. Proc. Amer. Soc. Test. Mater.*, 1933, **33** (2), 729. Tests show that the method with methylene blue has no value. *See under* Coal.

2527. **A Rapid Method for the Determination of the Specific Surface of Portland Cement.** Wagner, L. A. *Proc. Amer. Soc. Test. Mater.*, 1933, **33**, 570. Describes Wagner turbidimeter, which is based on transmission of light through kerosene emulsion.

2528. **Wanted, An Index for Measuring the Surface of a Mineral Powder.** Weinig, A. J. *Engng Min. J.*, 1935, **136**, 336–42. Since screen sizing, grain counts or sedimentation analysis alone are not a sufficient basis for calculating surface area, the author suggests methods for relating surface to weight. The method of deducing shape factors is given, and charts for evaluating surface area from the resulting data are given for several minerals.

2529. **Converting a Number Distribution for Particle Size into One for Volume or Surface Area.** Wise, M. E. *Philips Res. Rep.*, 1954, **9** (3), 231–7. A number distribution of equivalent radii of particles in a powder can be accurately converted into a distribution by volume or surface area, even if the data are highly and/or non-uniformly grouped. Formulae are derived to do this and applied to microscope analysis into frequency distribution of radii between 1, $\sqrt{2}$, 2, $2\sqrt{2}$, 4 . . . units. Illustrations, tables.

2530. **The Absolute Determination of the Specific Surfaces of Powders with the Blaine Apparatus.** Zagar, L. and Schumann, C. *Zement-Kalk-Gips.*, 1954, **7** (7), 282–4; *Glückauf*, 1954, **90** (43/44), 1436.

Classification

SIEVING, SCREENING

2531. **Test Sieves.** *British Standard* 410:1943, Amendment No. 4, 1955. Dimensions of wire cloth for normal sieves, methods of examination of cloth, and dimensions for perforated plates are given. Dimensions for A.S.T.M. sieves are tabulated in an appendix.

2532. **Methods for the Use of B.S. Fine-mesh Test Sieves.** *British Standard* 1796:1952. Methods of use, weight of sample, end point of test by hand sieving and machine sieving, and method of reporting results are specified.

2533. **Standard Specification for Sieves for Testing Purposes. Wire cloth, round hole and square hole screen and sieves.** *A.S.T.M. Book of Standards*, 1944, Part III, pp. 1048–54. A.S.T.M. Design Ell-39.

2534. **Standard Test Sieves.** *Handbook of Mineral Dressing.* TAGGART, A. F. 1945, Wiley & Sons, New York; Chapman & Hall, London. Sect. 19, pp. 100–3. Tables for comparison of specified dimensions for the Tyler, U.S. and British Engineering Standards Association series of wire-mesh sieves.

The Tyler series is based on openings of $\sqrt{2}$ progression, commencing with an opening of 74 microns (200 mesh). A series based on a $\sqrt[4]{2}$ progression commencing at the same opening is manufactured in order to give closer sizing. The Tyler series is standardized by the U.S. Bureau of Standards.

The U.S. series (A.S.T.M. Standard) is based also on a $\sqrt{2}$ ratio of opening dimension, but commences with an opening of 1000 microns (1 mm). This series can be used interchangeably with the Tyler Standard sieve series, owing to the range of permissible wire dimensions.

The British Standard series superseded the older Institute of Mining and Metallurgy series in 1932. The openings in the screens closely follow those in the Tyler series, the slight differences being due to the more restricted British range of British Standard wire diameters. Specifications for round-hole sieves (A.S.T.M. 311–39) are described.

2535. **Vibrating Machines for Conveying and Screening.** *Allg. Bauztg.*, Mar. 1955, **10**, 445. The principle is that of two masses swinging in resonance. Summary in *E.P.A. Technical Digest*, No. 41, June 1955, **1.**

2536. **Electrical Heating of Screens.** *Brit. Clayw.*, 1954, **62** (1), 311–3. Using step-down transformers, a heavy electric current is passed through the mesh wires, at low voltage. The screen is heated uniformly. Photographs.

2537. **Particle Size Distribution in Powder Metallurgy.** ANON. *Ceramic Age*, 1948 **51** (6), 324–8. Powders exposed to a nearly saturated atmosphere (water) for 72 hours were found to leave from 3 to 6% *less* on various sieves than did oven-dried material. Cumulative weight distribution curves of sponge iron, based on average openings of certified sieves showed better agreement between different sieves than comparisons based on nominal openings.

2538. **Tar Separator with Gyratory Screen.** *Chem. Processing*, Nov. 1955, p. 4. To avoid the troublesome cleaning of the settling tanks, the solids were screened out of the tar before going into the tanks by a gyratory screen, 120 mesh, at 1500 rev/min, around circle of $\frac{3}{16}$ in. diameter. A vortex is formed at each mesh aperture, which allows drainage by vortex motion and violently repels stones etc., which are helped off the screen by nylon brushes. The cleaning and filtering machine was supplied by

Russell Constructions, Ltd., to the Beckton Gas Works; 4–5 lb of solid are separated from 1000–1500 gallons of roughly separated tar per hour. After ten million gallons, no cleaning of the sieve was necessary, and the time to get the moisture content down to 5% was much reduced. The former blanketing of the steam coils by the solids was thus avoided.

2539. **Symposium on Air Classification.** *Min. Engng.*, 1957, **9**(10), 1112–28. Papers by A. L. Hall, R. E. Payne, W. H. Lykken and A. R. Lukens.

2540. **A New Classifier.** *Chem. & Engng News*, 1956, 24 Nov., 5880. In the new Sharples classifier the material is fed on to a rotating saucer, which throws the material out through ports into a rotating air stream passing in from one side of the vessel and out through the bottom carrying the finer material, the coarser material moving to the outer part of the vessel and collected separately. Adjustable feed and air flow are claimed to give a very sharp cut at all rates of feed.

2541. **Vibrator Screens Heated Electrically.** *Engineering, Lond.*, 30 April 1954, 596. Clogging is avoided. The firm of Henry Hawkins, Cannock, has used the screen for clay for tile making without supervision since Aug. 1953. The supply is from a Woden Co. 12 kVA transformer, air-cooled, single-phase, totally enclosed. Six tappings provide for variation according to size of mesh and moisture in clay.

2542. **Vibrating Screens.** *O.E.E.C. Technical Resistance Mission*, No. 127, Mining and Dressing of Low Grade Ores. App. IIIC. A summary is given of a lecture by Dr Decker of Klockner, Humboldt, Deutz, on theoretical aspects of vibrating screens, in which he attempts to analyse the movements of particles and the forces acting.

2543. **Nomogram for Conversion of Sieve Standards of B.S., I.M.M., A.S.T.M., Tyler, A.F.N.O.R., D.I.N. (Old), D.I.N. (New).** *Z. Erzbergb. Metallhüttenw.*, 1955, **8** (4), 194–5. The bases of the wire and opening dimensions are given and a tabulated comparison is given for Tyler., A.S.T.M., I.M.M. and B.S. sieves.

2544. **Theory of Screening.** Almin, K. E. *Svensk. Papp-Tidn.*, 1954 (2), 37–40. The capacity problem in series screen cascades.

2545. **On Mesh Size and Particle Size.** Andersen, J. *Zement.*, 1931, **20**, 224. Tabulated data show how the quantity per minute through a given sieve decreases sharply with time, but how the particle size (diameter) increases with time by 15% and 25% respectively in two experiments, fine and coarse particles respectively.

2546. **Considerations and Observations on the Manner of Operation of Shaker Sieves.** Andreasen, A. H. M. *Sprechsaal*, 1927, **60**, 515–7. The movement of a shaker sieve is analysed mathematically. Uniform results are difficult to attain in testing, the movement of the sieve is often quite complicated and solutions of some difficulties have not yet been reached. Curves are presented showing the relation between variables and sieving performance. [P]

2547. **Some Investigation into Attrition during Sieving.** Andreasen, A. H. M. *Sprechsaal*, 1928, **61**, 299. The possibility of deriving a standard mechanical procedure is discussed, and the possibilities of adding a cleaning material explored.

2548. **Improvements Relating to the milling of asbestos and the like Fibrous Bodies.** Asbestos Extraction and Machinery, Ltd. (S. Africa). *Brit. Pat.* 705998, 1952/54. The patent concerns a revolving dry cylindrical screen under vacuum. *See under* Asbestos.

2549. **Developments in Sieving Processes.** Batel, W. *Z. Ver. dtsch. Ing.*, 1955, **97** (13), 393–400; **97** (14), 417–24.

(1) Properties of moist feed and resulting phenomena on the vibrating sieve. The forces at the regions of particle contact, due to capillary effects of surface moisture, are analysed and illustrated by graphs. The relation between sieve performance, the moisture-content and temperature is analysed and illustrated for quartz and coal and

recommendations are made either to increase the sieve energy or dry the material beforehand. 36 figs, including photographs, diagrams, graphs and 10 refs.

(2) Sieve Blockage and its Clearance. The sieving is hindered not only by aggregation of particles but by blockage. The influence of capillary effect on blockage is illustrated diagrammatically and by photographs; and the forces acting are analysed. The influence of the mesh size on the sieve performance at different temperatures and moisture contents of the feed are shown graphically; the various effects, i.e. energy consumption, mesh size, capillary forces, of electric and inductive heating of the sieve are discussed, and the effects of increasing the vibration amplitude are described. 28 figs, 16 refs.

2550. **Experimental Investigations with Screens. A Study of the Factors Affecting the Capacity of Vibrating Screens.** BAUMAN, V. A. *Quarry Mgrs' J.*, 1951, **35**, 41–50; *Mech. Constr., Moscow* (*Mekhan. Stroit*), 1950, **7** (3), 13–8. A slightly condensed translation from the Russian (F.A. Shergold, Road Research Laboratory). The factors studied experimentally were: amplitude, frequency, size and shape of screens, percentage undersize in the feed, variability of feed, inclination of screen method (wet or dry), particle shape and moisture content of feed. Tabular and graphical representation of results. An empirical formula is derived for calculating the capacity of vibrating screens in the normal range of working conditions.

2551. **Requirements of Sieves of Vibrating Screens.** BAUMAN, V. A. *Mech. Constr., Moscow* (*Mekhan. Stroit.*), 1951, **8** (2), 22. Factors affecting the efficiency of woven-wire screens are examined and results are tabulated of tests on the wearing properties. [P]

2552. **The Theory of Unbalanced Vibration and its Application to a Small Vibrator for General Use.** BERTHIER, R. M. *Rev. Matér. Constr.*, 1950 (422), 332–4. Discussion of eccentrically-balanced vibrators for feeding difficult powders to and from grinding mills.

2553. **The Principles and Applications of a Revolutionary Screening Device.** BRANT, D. G. *Bull. Amer. ceramic Soc.*, 1953, **32** (8), 267–71. The device utilizes accurately controlled gyratory motion in horizontal and vertical planes. Phenomenal screen cloth life and highly efficient and economical operation on both wet and dry screening has resulted in wide acceptance. The applications to ceramic materials in slip and slurry form are emphasized. Well illustrated diagrammatically. (The Sweco Screen.)

2554. **Comparison of the Test Sieves of Different Countries.** BREWER, R. E. *Rep. Invest. U.S. Bur. Min.*, No. 3766, 1944, 5 pp. Britain −2, U.S.A. −2, Germany −1, France −1. Tabulated comparison.

2555. **Methods of Sieve Analysis with Particular Reference to Bone Char.** CARPENTER, F. G. and DIETZ, V. R. *J. Res. nat. Bur. Standards*, 1950, **45**, 328–46. The effective size of the sieve is determined by calibrated glass spheres. Could be applied to cement, etc.

2556. **Glass Spheres for the Measurement of the Effective Openings of Test Sieves.** CARPENTER, F. G. and DIETZ, V. R. *J. Res. nat. Bur. Standards*, 1951, **47**, 139–47. The effective opening of test sieves is generally somewhat larger than the nominal opening. A calibrated mixture of glass spheres is used. Statistical analysis showed reproducibility and accuracy to be within about 1%.

2557. **Apparatus for Classifying Granular Substance.** CORNWALL MILLS, LTD., VARCOE, M. *Brit. Pat.* 653020, 1951/52. The walls of the sieving chamber are partly constructed of sieving mesh, and a blast of air directed downwards into the chamber produces a vortex and forces the particles through the mesh.

2558. **Elimination of Screen Blinding by Application of Electric Heat.** CRAIGLOW, G. W. *Br. Clayw.*, 1951, **60**, 37. *See also Bull. Amer. ceramic Soc.*, 1950, **29**, 27.

2559. **Theory of Sieving and Grading of Materials.** DALLAVALLE, J. M. *Micromeritics*, Chap. 5, 1948, 2nd Ed. Pitman, New York.

2560. **The Dynamics of Screening.** DAVIS, R. F. *Trans. Instn chem. Engrs, Lond.*, 1940, **18**, 21–4. A mathematical analysis of the motion of particles on a horizontal screen, and of the motion on an electrically-vibrating screen, are presented graphically.

2561. **Standardization of Testing Sieves.** DJINGHEUSIAN, L. E. *Canada. Min. J.*, 1953, **56**, 283–85. A procedure is suggested.

2562. **Electrical Heating of Screens for Sieving Ground Clay.** DMITRICHENKO, N. S. and SHAVRINOV, M. A. *Fireproof Mat., Moscow* (*Ogneupory*), 1952, **17**, 421. To reduce dust and for other reasons, a Russian plant had to increase the moisture content of ground clay to 10–12%. Screening was then impossible with sieves of 2×2 mm mesh. A method of electrical heating is described.

2563. **Portable Field Sieve.** ENDECOTTS (FILTERS), LTD. *Industr. Diam. Rev.*, 1955, **15** (179), 198. A new sieve has interchangeable bottoms and area of 12 sq. in. Screens are fixed by clamps for quick exchange.

2564. **Hanna Iron Ore Co. Uses Heated Screens to Dryscreen Wet Sticky Ores.** ERICKSON, S. E. and TANAMACHI, M. *Min. World* (*San Francisco*), July 1952, **14**, 47–9. The changes necessary to convert to a heated deck operation, current supply and the securing of uniform current distribution are discussed. The screening efficiency of wet iron ore was considerably increased.

2565. **The Curved Sieve. A New Apparatus for Wet Screening of Fine Sizes.** FONTEYN, F. J. *De Ingenieur*, **68** (5), 1–5. 3 Feb. 1956. The Coal Preparation Division of the Netherlands State Mines has recently developed an apparatus consisting of a fixed curved sieve with tangential supply of feed. It has proved successful for differing purposes. Because of its simplicity, good screening performance and low installation and operating costs it should find many applications for separating mixtures of solid and liquid. *See also Glückauf.*, 2 July 1955, **91**, 781–6.

2566. **Principles of Mineral Dressing.** GAUDIN, A. M. 1939, McGraw-Hill, New York. Chap. 3, Laboratory sizing.

2567. **Theoretical Precision of Screen Analysis Results.** GAYLE, J. B. *Rep. Invest. U.S. Bur. Min.*, No. 4933, 1952; *Instn. Min. Metall. Abstr.*, Dec/Jan. 1954/5, **5** (2), 85. The paper describes the application of probability formulae to determine the theoretical standard deviation of screen analysis results.

2568. **Enamelled Screen Gives Best Results in Screening Coke Breeze and Damp Materials.** GEYER, F. G. *Blast Furn.*, Dec. 1946, **34**, 1529–30. In screening coke, the cloth wires become so hard that they cannot be cleared by brushing. Vitreous enamel increased the life from 24 hours to 11–15 days, and Hersite enamel gave 55 days' service.

2569. **Comparison of Dry and Wet Sieving of Mixed Aggregates and Fillers Used in Bituminous Mixtures.** GOUGH, C. M. *Rd & Rds Constr.*, 1955, **33** (393), 282–8.

2570. **Milling Machines and Material.** GROHN, H. *Farbenztg.*, 1930, **35**, 2328, 2376, 2424. By the use of test sieves of varying mesh, the costs of milling to any size can be calculated.

2571. **A Study of Size Analysis by Sieving.** HEYWOOD, H. *Trans. Instn Min. Metall., Lond.*, 1945–6, **15**, 373. A study of particle size and shape, and the relation and effects of these during the sieving operation.

2572. **Application of Sizing Analysis to Mill Practice.** HEYWOOD, H. and PRYOR, E. J. *Bull. Instn Min. Metall., Lond.*, Mar. 1946, No. 477, p. 10. Fundamental data derived from laboratory screening should aid the interpretation of control tests and facilitate studies of mill practice.

2573. **Filter Efficiency and Standardization of Test Dust.** HEYWOOD, H. *Proc. B. Instn mech. Engrs, Lond.*, 1952/3, 1B, 169–174. Basic theory for the efficiency of air cleaners is developed. Knowledge of the intrinsic efficiency of a filter enables a mass efficiency of collection to be calculated for any given size composition of dust burden. The formulation of a standard dust specification for testing cleaners and filters has been developed, and the specification is incorporated in British Standard 1701:1950. The object has been to ensure that the test dust contains some of all the particle sizes that are likely to be encountered in the practical operation of vehicles and aircraft. Limits are given for cleaners of 'Moderate Efficiency' and for 'High Efficiency'.

2574. **Vibratory Classifier.** HOLMAN BROS., LTD. *Engineering, Lond.*, 7 Aug. 1953, **176** (4567), 189. After removal of oversize on a screen, the required material is separated into two grades on one vibrating screen and then into four grades on two more vibrating screens arranged suitably below the first.

2575. **Beneficiation in 1950.** HOLT, G. J. *Min. Engng, N.Y.*, 1951, **3** (190), 122–5. The introduction of electrically-heated screens by Tyler permits the feeding of moist materials without blinding the screen.

2576. **Gyratory Sieve.** HURST, J. *Chem. Age, Lond.*, 19 Dec. 1953, **69**, 1273–6; *Confect. Prod.*, Jan. 1954, 63–7. The gyratory motion of a freely suspended out of balance fly-wheel provides small amplitude rotations to sieving devices and appears applicable to innumerable separation operations, to liquid and viscous materials as well as to powders of all degrees of dryness or oiliness. Outputs 14 to 18 times greater than with shaker screens are said to be obtainable, due to the particles moving in concentric paths close to the screen which prevents blinding of the mesh. Difficult materials can now be screened through a fine mesh. The gyratory motion of the screen is imparted by a fly-wheel rotating at about 1000 rev/min with a $\frac{1}{4}$-h.p. motor. The screen moves in a small circular orbit, say $\frac{3}{16}$th in. in a horizontal plane.

2577. **Separation of a Mixture on an Inclined Oscillating Grid.** INST. F. TECH. FORSCH. UND ENTWICK. Sage & Co., Salzburg. *Belg. Pat.*, 510815, 1952/53. The separation depends on physical characteristics of the constituents (and whether dry or moist), as they are able to receive more or less displacement on the upward movement of the vibrating sieve.

2578. **Mechanical Wet Sieve Testing Method.** KOBLISKA, J. J. and RODENBERGER, H. J. *Bull. Amer. Soc. Test. Mat.*, No. 200, Sept. 1954, 46–7. A mechanical testing device has been designed to eliminate causes of variable results in wet sieving, to decrease working time and to standardize the end point. After wetting, pasting and dispersing in the preferred liquid, the slurry is transferred to the sieve, which is revolved at constant speed, say 20 rev/min, and sprayed at a predetermined rate, say 4 litres/min, and the process stopped after a definite time, say 15 minutes. The residue is dried and weighed in the usual manner. Diagram comparisons of results are tabulated.

2579. **Evaluating the Performance of a Screen.** KOHN, R. *Engng Min. J.*, 1942 (143), 60. An improved graphical method is suggested.

2580. **Performance and Energy Consumption of a Sieving Machine as a Function of the Composition of the Material.** LANGERBEIN, H. *Aachen Blätter*, 1954, 4 (1/2), 19–52. The characteristics of the sieve, its frequency and dimensions are embodied in a diagram which is intended to enable a desired sharpness of grading to be achieved. Abstract in *Glückauf.*, 1954, **90** (29/30), 813.

2581. **The Resonant Vibrating Screens and their Development during the Last Ten Years.** LINKE, G. *Glückauf.*, 15 Jan. 1949, **85**, 45–51.

2582. **The Screening and Grading of Materials.** LISTER, J. E. 1924, Ernest Benn.

2583. **Influence of Sieving Time on the Accuracy of Test Sievings.** LOEHN, H. and BACHMANN, H. *Freiburger Forschungsheft*, 1954, A22, Aufbereitung, pp. 58–70;

Glückauf., 1954, **90** (25/26), 704. The important concepts of analytical sieving are explained. Errors in sampling and weighing, and losses in sieving are considered. Experimental determination of the optimum sieving time.

2584. **Test Sieves.** McCalman, D. *Industr. Chem. Mfr*, 1937, **13**, 464. The accuracy of sieve testing. 1938, **14**, 64. The manufacture of test sieves, 1938–9, **14–15**, 231, 161. An investigation of British Standard test sieves.

2585. **Improvements in and Relating to Screens and Sieves.** McCarthy, C. P. *Brit. Pat.* 705367, 1949/54. The longitudinal members or bars are pressed into slots in the cross-members and so are easily replaced.

2586. **The Theory of Screening Efficiency.** Michelin, F. *Rev. Industr. min. Memoire*, Sept. 1945, **502**, 317–39. The theory is based on the laws of probability. Screening efficiency is evaluated from material data. For optimum efficiency at a theoretical size *m*, a slightly greater mesh must be used. *M. M–m* is calculable.

2587. **Clogging of Screens by Resonance of the Cloth for Large Throughputs.** Michelin, F. *Rev. Industr. Min.*, 1951, **31**, 650. Paper to International Conference on Coal Preparation. June 1950, Institute of Fuel. A mathematical theory is given for the clogging of high-frequency vibrating screens by resonance effects, which are determined by the distance between the brackets, the tension of the cloth and the load on the cloth.

2588. **New Trends in the Field of Preparation.** Moelling, H. A. *Progressus*, 1953, **5**, E5, 22. The Esch Screen (Magneta) vibrates at 3000 per minute, by means of an oscillation transformer which converts the mains oscillations into circular or elliptical mechanical oscillations through a number of specially arranged electromagnets. The efficiency is approx. 150% of previous designs, and with less weight.

2589. **A Survey of Sieve Sizes and Grade Scales.** Morey, R. E. *Trans. Amer. Foundrym. Ass.*, 1948, **56**, 286–96. A uniform grading system, combining the best features of existing systems is proposed.

2590. **On the Accuracy of Sieve Analysis made by Means of Sieving Machines.** Mortsell, S. *K. tekn. Hogsk Handl.* (*Trans. Royal Institute of Technology, Stockholm*), 1948, No. 17, 45 pp. *Bull. Instn Min. Metall., Lond.*, A93, Sept. 1950. The main factors governing accuracy have been tested and are described.

2591. **Factors Governing the Particle-size Grading of Pulverized Materials.** North, R. *Industr. Chem. Mfr*, 1948, **24** (1), 5–11. Observations and data are based on experience gained with commercial installations by International Combustion, Ltd. A substantial difference is evident between the particle-size grading of powders which have been classified by air separation and those which have been sized by screening. Air-separated products contain no superfine particles. [P]

2592. **Classification of Broken Ore.** Pohl, H. *Stahl u. Eisen*, 1955, **75** (20), 1295–1300. Round holes and mesh sieves are compared. Appreciable differences exist. A table shows the considerable differences in sieve areas, and other dimensions and the percentage errors in amounts passing.

2593. **An Experimental Study in Sieving.** Porter, J. B. *Rep. nat. Res. Coun. Can.*, No. 22, 1928. An extensive series of large-scale tests, varying one factor at a time. The results obtained are of theoretical and practical value in the design and operation of screens.

2594. **Characteristics of Screen Circuit Products.** Reed, A. E. *Trans. Amer. Inst. min. (metall.) Engrs*, 1946, **169**, 160–70. A discussion with diagrams of circuits and graphical and tabular representation of results.

2595. **The Importance of Sieve Bottom in the Sieving Technique. Pt 1. Perforated Plates. Pt 2. Sieving Fabrics and Special Sieve Bottoms.** Riedel, E. *Erdöl u. Kohle*,

1952, **5**, 171–3, 222–6. A review of German progress in the development of non-clogging sieves. The latest innovation is the Conidier sieve, which has conical holes with their axes inclined at 75° to the horizontal. Rubber fabrics for certain purposes have longer lives than metal fabrics. Other designs and advantages are described.

2596. **The Ultra Resonant Sieve.** RIEDLE, V. and LAUENSTEIN, H. *Erdol u. Köhle*, 1952, **5**, 98–100. A simple sieving machine is used with undamped springs and an operational speed above that of resonance. 3–3·5 kW were used for moving 20 tons/h over a length of 12 metres, whereas only 25% of this power was used at idling. The machine has been used uninterruptedly for nearly two years.

2597. **Calculations on Stamped and Woven Sieves.** ROTFUCHS, G. *Zement*, 1934, **23**, 670–2. Tabulated data and graphic comparisons are made.

2598. **Investigations into Sieve Analysis of Sands, and the Presentation of Results.** SCHNEIDERHOHN, P. *Neues Jb. Miner.*, April 1953, **85** (2), 141–202.

2599. **Screening, Grading and Classifying.** SCOTT, R. A. *Chemical Engineering Practice*, Vol. 3, Chap. 6, pp. 128–71. Butterworths Scientific Publications, 1957. An analysis of the mechanism of screening, with screen construction and tables of mesh apertures. Machines for screening and grading are described and illustrated. The mechanism of the settling of particles in fluids is then analysed and the laws of movement of particles in fluids enunciated. 10 refs.

2600. **Efficiency of Screening Operations for Road Making Aggregates.** SHERGOLD, F. A. and HOSKING, J. R. *Engineer, Lond.*, 24 Aug. 1956, 258–60. No general formula exists for expressing the efficiency of screening operations. A method has been developed at the Road Research Laboratory, D.S.I.R., for measuring efficiency in the screening of road-making aggregates. A formula for efficiency has been developed, based on certain sieving characteristics of the feed material.

2601. **Theory of Screening.** (In English.) STECNBERG, B. *Svensk Papp-Tidn.*, 1953 (20), 771–8. Principles of screening system design.

2602. **65-Mesh Grinding with Stainless Steel Screens.** STEPHEN, W. H. *Trans. Amer. Inst. min. (metall.) Engrs*, 1939, **134**.

2603. **Screens and Separators.** STURTEVANT ENGINEERING CO. Publication 1598, 1930, 30 pp.

2604. **Principles of Vibrating Screen Practice.** TURVEY, J. G. *Trans. ceram. Soc.*, 1935, **34**, 250–65.

2605. **Filtration of Very Fine Dust.** VOKES, LTD. *Engineering, Lond.*, 1955, **179** (4659), 607. The Vokes 55 'Absolute' air filter consists of esparto grass based paper with proportion of finely-corded long asbestos fibres, giving high dust-retention (less than 5 microns) and low flow restriction. Illustrations.

2606. **A Precise Method for Sieve Analysis.** WEBER, M. J. and MORAN, R. F. *Industr. Engng Chem. (Anal.)*, 1938, **10**, 180–4. Testing sieves, even though to A.S.T.M. standards do not give accurate results without calibration. Methods of check by standard samples are not satisfactory. A method has been developed by use of microscope, for determining the effective opening of plain-weaved sieves, and the value is independent of the size distribution of the material to be tested. Further work to improve accuracy should be done. Mechanical sieve shapers should be used for reproducibility and accuracy and 100 g is a convenient quantity.

2607. **Determination of Cloth Area for Industrial Air Filters.** WILLIAMS, C. E., HATCH, T. and GREENBERG, L. *Heat. Pip. Air Condit.*, 1940, **12**, 259–63.

2608. **Method of Preparation and Fractionation of Glass and Silica Spheres.** WILLIAMS, P. S. *Disc. Faraday Soc.*, 1951, **11**, 49. The powdered material is blown through a flame to make the grains spherical and then allowed to impinge against a vertical plate which was slotted horizontally for size separation.

CENTRIFUGAL AND CYCLONE SEPARATION

2609. **Bibliography of the Liquid Solid Cyclone.** *J. chem. Soc. S. Afr.*, Feb. 1956, **56** (8), 299–302. An assembly of 105 references is compiled by O. F. Tangel and R. J. Brison of Battelle Memorial Institute, for the years 1948–54.

2610. **Classifier Uses New Theory.** *Chem. Engng*, 1953, **60** (3), 384–6. Described M. H. Hebb's invention U.S. Pat. 2616563 assigned to the Sharples Co., wherein the classifying space above the cone tapers to the centre. Directing baffles are placed at the inlets. Calculations, based on physical properties of the fluid and solid components, for cross-sectional area of the classifying space are given.

2611. **Spiral Sizes Powder Clearly.** ANON. *Chem. Engng*, April 1956, 236. The Alpine Mikroplex spiral classifier is stated to cut clearly at any size from 325 mesh to 2·5 microns. Efficiency is better than 70% for cuts coarser than 5 microns as compared with less than 60% efficiency at 50 microns with other air classifiers. The separating chamber is divided by spaced vanes, the air passing in on the outside of the vanes, the feed passing on the inside, and being caught up by the air passing through the vanes. High uniformity in the air-flow pattern is stated to eliminate drag turbulence, and is a feature of the rotating separation chamber.

2612. **Producing Superfine Powders.** *Edg. Allen News*, 1946, **24** (284–5). Description of the 'Rema' air classifier. The air stream ascends in a spiral and the material descends in a contracting and expanding helix. Construction, operation and performance are described. Applications are also described and a table of mechanical details of 12 standard machines is given.

2613. **Symposium on Dynamics of Fluid Solid Systems.** *Industr. Engng Chem. (Industr.)*, 1949, **41**, 1099–1249. *See* p. 1108.

2614. **From Open to Closed Circuit Grinding with Liquid Cyclones.** ANON. *Rock Prod.*, 1953, **56** (7), 62–6. *See under* Open v. Closed Circuit. [P]

2615. **Hydraulic Classification of Powders.** *Sci. Libr. Bibliogr. Ser.*, 1939, No. 473, 622·75. 46 refs from 1933–7.

2616. **Colloquium on Cyclone Separation. Delft 27 Jan. 1953.** ANON. *TonindustrZtg*, 1953, 77 (3/4), 58–9. Full summaries of 8 contributions are given (none English). One contribution is on the hydrocyclone.

2617. **Problems of Cyclone Separators.** Verein Deutsche Ingenieur Fachauschuss für Staubtechnik. Tagungsheft 3. 27 Jan. 1953. Duisberg.

(1) Researches into Cyclone Separators. Prof. A. J. ter Linden, Delft. (2) Pressure losses and separation capacity of Cyclone Separators. Dr. Ing. W. Barth, V.D.I., Karlsruhe. (3) Determination of pressure losses in Cyclone Separators. Dr. Ing. G. Weidner, Karlsruhe. (4) Possibilities of recovery of draft energy of Cyclone Separators. Dr. Ing. O. Schiele, Karlsruhe. (5) The effect of dust content on the degree of dust elimination. Dr. Ing. H. van der Kolk, V.D.I., Helmstede. (6) The influence of the solid materials on pressure drop. Dr. Ing. R. Nagel, V.D.I., Offenbach a/M. (7) Researches on the Hydrocyclone. Dr. Ing. G. Hausberg, V.D.I., Essen. Discussion, pp. 33–9, 87 refs. to literature, 9 refs. to books, etc.

2618. **The Practical Application of Hydrocyclones in Milling Circuits on Sundry Gold Mines.** ADAMSON, R. J. and MORTIMER, J. H. *J. chem. Soc. S. Africa*, Oct. 1955, **56** (4), 169–181. Symposium on Hydrocyclones. During the period Jan. 1953 to June 1955, hydrocyclones have replaced orthodox classifiers to varying degrees in eleven milling plants. Diameters were from 12 to 36 in. and the types were (1) 20° angle cones and (2) cylindrical. The seven main advantages are itemized: (1) reduction in gold locked up in the milling circuit; (2) higher mineral concentration in underflow; (3) reduction in maintenance costs; (4) minimum of pulp circulation; (5) reduced labour, e.g.

greasers; (6) less opportunity of theft of gold concentrate; (7) lower accident risk; (8) very low initial cost; (9) easy adaptation for experimental purposes; (10) experiments can be conducted without disturbing plant equipment. Performance at the various plants is presented in tabular form. [P]

2619. **Hydraulic Classifiers as an Aid to Batch Grinding: Some Possible Economies in Grinding Pottery Material.** ANDREWS, L. *Trans. ceram. Soc.*, 1931, **30**, 98–111. During an 8-hour grind on a pan mill, the material was examined at 2-hour intervals, and the relative proportions of different grain-sizes, the relative quantities of −10 mu materials produced, and the relative increases in the surface of the material for each successive period were determined. A simple hydraulic classifier for use with existing pan mills or cylinders is described, and its advantages are pointed out. A rapid laboratory elutriator for continuous works use is also described.

2620. **Classified Grinding Research.** ANDREWS, L. *Trans. Instn Min. Metall., Lond.*, Forty-eighth Session, 1938–1939, 141–207. The theory is advanced that the rise in temperature in a wet-grinding mill is due to (1) molecular strain and shearing in the suspending medium; (2) molecular agitation in particles not fractured by the blows received. Results are given of laboratory experiments of works tests which appear to confirm the theory. The application of the theory to milling and classification practice is discussed and recommendations are made for research on these lines. A specification of the conditions with which classifiers for such research should comply, and the principle and design of suitable classifiers are discussed. Discussion 165–207. [P]

2621. **Notes on the Application of Hydrocyclones in the West Rand Consolidated Mines, Ltd.** ARTHUR, J. A. *J. chem. Soc. S. Afr.*, Feb. 1956, **56** (8), 295–99. The results of installing a 27-in. 20° cyclone in the secondary milling circuit for replacing two bowl classifiers and increasing output are presented in tabular form.

2622. **A Technique for Entraining Fine Powders in an Air Stream at a Constant Rate.** ATKINS, B. R. *J. Sci. Instrum.*, 1951, **28** (7), 221. A laboratory unit for delivering dry coal powder into an air stream at a controlled rate of about 1 lb/h.

2623. **A Simple Method of Separation of Particles between 1·0 and 0·01 Micron.** AVY, A., RAILLIÈRE, R. *Chim. et Industr.*, 1953, **69** (3), 431–4. Method and calculations are given for sizing by use of a centrifuge at 6000 rev/min. Results are tabulated and embodied in curves on a logarithmic scale showing size distribution by numerical and weight evaluations. There is good agreement between the curves for each method using indigo. The fractions separated after centrifuging from 1 minute to 1 hour are weighed, and diameters, etc., calculated from the weights and the times of centrifuging. The method is considered sufficiently rapid and accurate. *See also* Donoghue and Bostock, Particle Size Determination.

2624. **Classification of the Grinding Process in Oscillating Mills with Wet Charge.** BACHMANN, D. *Verfahrenstechnik*, 1940, No. 3, 82–9. Model experiments with different types of balls and mills and grinding experiments with marble suspensions (20%) are described. Calibration experiments showed that the fineness of the charge could be read as a function of the observed setting line. 21 refs. *See Bull. Brit. Coal Res. Ass.*, 1941, **5** (4), 79, L.478.

2625. **Separation by Centrifugation in Dense Media. Pilot plant trial at Gottelhorn, Saar.** BELUGON, P. Note Technique, Centre d'Études et Recherches des Charbonnages de France, May 1949.

2626. **Classification by Air.** BLARE, E. C. *L'Équipement Mécanique*, 1951, **29** (255), 11–23. A detailed theoretical study of the physical phenomena on which air classification is based is given, and different designs of classifiers are described. Air classifiers begin to be useful at 0·5 mm. Economic use industrially begins at 0·2 mm.

2627. **Improvements in or Relating to Classifiers Particularly for Use in Grinding or**

Pulverizing Solids. Blaw Knox Co. *Brit. Pat.* 634723, 1946. A classifier for connection to an impact pulverizer in a closed circuit with a spreader cone in the housing with an outlet for floating particles and a hopper for oversize to be re-circulated.

2628. **Calculating Classifier Data.** Bond, F. C. *Engng Min. J.*, 1950, **151** (12), 90.

2629. **Short Column Hydraulic Elutriator for Subsieve Size.** Cooke, S. R. B. *Rep. Invest. U.S. Bur. Min.*, No. 3333, Feb. 1937, 39–51.

2630. **Cyclone Operating Factors and Capacities on Coal and Refuse Slurries.** Dahlstrom, D. A. *Trans. Amer. Inst. min. (metall.) Engrs*, 1949, **184**, 331–44.

2631. **High Speed Classification and Desliming with the Liquid Solid Cyclone.** Dahlstrom, D. A. *Trans. Amer. Inst. min. (metall.) Engrs*, 1951, **190**, 153–65.

2632. **High Efficiency Desliming by Use of Hydraulic Water Additions to the Liquid Solid Cyclone.** Dahlstrom, D. A. *Min. Engng, N.Y.*, 1952, 4 (2), 788–93. Results described and tabulated of the experimental work on the two-stage process for more efficient removal of slimes from valuable solids where economies require smaller size recovery. [P]

2633. **The Theory of Pneumatic Conveying.** Dallavalle, J. M. *Heat & Ventilation*, 1942, **39**, 28–32.

2634. **Classification in Hydrocyclones.** Darby, G. M. *Bull. Amer. ceram. Soc.*, 1955, **34** (9), 287–90. The paper discusses the history and development of liquid solid cyclones and their operations as classifiers.

2635. **The Efficiency of Cyclone Dust Separators.** Dauphin, J. *Génie Chimique*, 1955, **73** (5), 121–9. The dust is characterized not by its diameter or speed but by a parameter which has the dimensions of time. This parameter, when dealing with equations of movement in the cyclone, allows the theory of Rosin and of Muhlrad to be applied quite simply with regard to the intrinsic efficiency. The author then describes his own theory which takes account of the movement of the air, which is neglected in the preceding theories. He introduces the concept of the stationary particle, and obtains results for efficiency which agree with experiment. Mainly mathematical treatment. 4 refs.

2636. **The Separation of Airborne Dust and Particles.** Davies, C. N. *Proc. Instn mech. Engrs, Lond.* 1952, **1B**, 185–98. 50 refs. *See under* Dust Hazards.

2637. **The Application of the Liquid Solid Cyclone as a Classifier in Closed Circuit Grinding at Rand Leases (V) G.M. Co., Ltd.** Dennehy, M. J. and Kok, S. K. de. *J. chem. Soc. S. Afr.*, Mar. 1953, **53** (9), 261–84. An experimental investigation with the hydraulic cyclone in closed circuit grinding is reported. It proved possible to incorporate the cyclone in a plant designed for mechanical classification, at low cost and without interfering with current operations. The device can compete successfully with the more costly classifiers used in primary and secondary milling circuits. A number of advantages is discussed. Design and operation of the hydraulic cyclone are fully described and performance data are presented in ten tables. Diagrams, illustrations, discussion, 18 refs. [P]

2638. **Fine Grinding and Classification.** Dorr, J. V. N. and Arable, A. *Trans. Amer. Inst. min. (metall.) Engrs*, 1935, **112**, 161; *Milling Methods*, 1934.

2639. **Recent Developments in Classification and Fluidization as Applications of the Principles of Particle Dynamics.** Dorr, J. V. N., and Bosqui, F. L. Symposium on Mineral Dressing, London, Sept. 1952, Paper No. 10. Institute of Mining and Metallurgy. Description and illustrations of Dorr classifiers and separators and fluidized reactors. Eight tables of data on the operation of classifiers. 24 refs. Published in *Recent Advances in Mineral Dressing*, 1953, Institution of Mining and Metallurgy. [P]

2640. **The Use of Centrifugal Force for Cleaning Fine Coal.** Driessen, M. G. *J. Inst.*

Fuel, Dec. 1945, **19**, 33–47. Cleaning in heavy liquids and suspensions, with special reference to the cyclone washer.

2641. **The Use of Hydraulic Cyclones in Thickeners and Washers in Modern Coal Preparation.** DRIESSEN, M. G. *Trans. Amer. Inst. min. (metall.) Engrs*, 1948, **177**, 240; *Tech. Publ. Amer. Inst. Min. Engrs*, No. 2315; *Coal Tech.*, Aug. 1947.

2642. **Theory of Flow in a Cyclone. Influence of Turbulence and its Mathematical Interpretation.** DRIESSEN, M. G. *Rev. Industr. min.*, Mar. 1951, 449–61.

2643. **The Application of Centrifugal Forces to Gravitational Classifiers.** EMMETT, R. C. and DAHLSTROM, D. A. *Min. Engng, N.Y.*, 1953, **5** (10), 1015–21. A different approach to gravitational classification equipment has been proposed to afford more 'self-regulation' to the operation, enlarge capacity per square foot and possibly to increase sharpness of classification at no increase in power requirements. Experimental evidence indicates that this can be done. It is presented in graphic and tabular form. 8 refs.

2644. **Differential Grinding in a Cyclone Shown by Screen Tests.** ERICKSON, S. E. *Engng Min. J.*, 1954, **155** (1), 95, 168. A series of tables shows that in wet cyclones generally used for concentration, thickening, etc., a grinding can take place comparable with standard ball mill grinding, and with selectivity in output. A 6-in. cyclone was used.

2645. **Classifier Efficiency. An Experimental Study.** FAHRENWALD, A. W. *Trans. Amer. Inst. min. (metall.) Engrs*, 1930, **87**, 82–93. The inadequacy of sieve sizing as a basis of measuring classifier efficiency is discussed. Grain density and configuration are disturbing factors. The influence of these is shown mathematically, and an ideal classification diagram on the basis of size and specific gravity is presented. The purpose of the paper is to present a new experimental method of measuring classifier efficiency. This is based on an air elutriation method and is intended to measure the efficiency of removal of the finished product.

2646. **The Cyclone as a Separating Tool in Mineral Dressing.** FERN, K. A. *Trans. Instn chem. Engrs, Lond.*, 1952, **30**, 82–6. Results are given of tests carried out with 3-in. and 6-in. diameter cyclones on a variety of minerals in heavy suspension in order to test the effect of variables on separations. 4 refs. [P]

2647. **Operating Behaviour of Liquid–Solid Cyclones.** FITCH, E. B. and JOHNSON, E. C. *Min. Engng, N.Y.*, 1953, **5** (2); *Trans. Amer. Inst. min. (metall.) Engrs*, **196**, 304–8. The operating behaviour of liquid–solid cyclones is outlined, together with the nature and range of the process results obtainable. Flow and separation ranges expected in standard units are tabulated, and classification factors presented graphically against micron sizes.

2648. **The Hydrocyclone its Application and Explanation.** FONTEYN, F. J. and DIJKSMAN, C. Symposium on Mineral Dressing, London, Sept. 1952, Paper No. 18. Institute of Mining and Metallurgy. Includes 6 tables of data on various examples of separation. 8 refs. Published in *Recent Advances in Mineral Dressing*, 1953, Institute of Mining and Metallurgy.

2649. **Screening and Classification in Grinding Circuits.** GRAY, S. and ELLIOT, P. M. *Trans. Canad. Min. Inst. (Inst. Min. Metall.)*, 1946, **49**, 466–73. Description of classifying methods and plant data presented. [P]

2650. **Air Classification in Pulverizing.** HARDINGE, H. *Industr. Engng Chem. (Industr.)*, 1934, **26**, 1139–42.

2651. **Classifying Method for Pulverized Materials.** HARDINGE, H. *U.S. Pat.* 2381954, 1945. Centrifugal force is used to separate the oversize from the fines, while the fines which get carried along with the oversize are reclassified by means of the hindered settling principle.

2652. **Splitting the Minus 200 with Superpanner and Infra-sizer.** HAULTAIN, H. E. T. *Trans. Canad. Min. Inst.* (*Inst. Min. Metall.*), 1937, **40**, 229–40. *See under* Particle Size Determination.

2653. **A New Infrasizer.** HAULTAIN, H. E. *Trans. Canad. Min. Inst.* (*Inst. Min. and Metall.*), 1950, **53**, 78–81. Has only two cones instead of seven and splits 25 grams of sample into two portions in 30 minutes.

2654. **Classifier Uses New Theory.** HEBB, H. *Chem. Engng*, Mar. 1953, **60**, 384–6; *U.S. Pat.* 2616563, 1953. A centrifugal (vortex) classifier is designed on a calculated height of the classifying zone, based on a balance between centrifugal and drag forces. The feed air and solid particles are admitted tangentially around the periphery and are further subjected to rotation between tapering discs, spaced a short distance apart, and tapering to a thin section at the centre of rotation where fine materials are withdrawn. Rejects at the periphery drop through slots into a conical space beneath.

2655. **Liquid Cyclones.** HESLING, S. *Chem. & Process Engng*, 1952, **33** (9), 483–5. 11 refs.

2656. **Difficult Classification Problems are Solved with the Dutch State Mines Cyclone.** HOCHSHEID, R. E. *J. chem. Soc. S. Afr.*, Nov. 1955, **56** (5), 197–204.

2657. **Notes on the Infrasizer and Superpanner.** JONES, W. R. *Bull. Inst. Min. Metall., Lond.*, No. 431, Aug. 1940. 3 pp. The infra-sizer can split 200-mesh material into seven separate sizes, the finest being below ten microns. The adhesion of fine particles to each other is prevented by a ball and cone device. The superpanner separates materials of different specific gravities.

2658. **A Preliminary Study of the Motion of Particles in a Hydraulic Cyclone. Velocity Measurements in a Perspex Cyclone.** KELSALL, D. F. *Chem. and Process Engng*, 1952, **33** (5), 261; *Trans. Instn. chem. Engrs, Lond.*, 1952, **30** (10). These papers are amplified in the contribution of Kelsall at the Symposium on Mineral Dressing, London, Sept., 1952; published by the Institute of Mining and Metallurgy, 1953. The work of A. Fage and H. C. A. Townend, *Proc. roy. Soc. A.*, **135**, 656, 1932, is quoted.

2659. **A Further Study of the Hydraulic Cyclone.** KELSALL, D. F. *J. chem. Soc. S. Afr.*, Sept. 1955, **56** (3), 125–53. By a technique of injection of closely-sized batches of perspex spheres into the feed of a 3-in. hydraulic cyclone, the effect of several variables on solid elimination efficiency has been investigated. This paper is republished from *Chemical Engineering Science*, 1953, **2**, 254–72. It is shown that with a 3-in. cyclone, a ¼-in. diameter feed results in maximum efficiencies for a wide range of conditions; it is considered impossible to derive simple power relationship to describe the effect on particle elimination efficiency of change in feed diameter, overflow diameter and throughput, to cover a range including optimum conditions. The importance of turbulent conditions in the feed and of short circuiting flow have been demonstrated.

2660. **Pulverulent Material Classifying Means.** KENNEDY VAN SAUN MANUFACTURING AND ENGINEERING CORPORATION; NIEMITZ, G. *Brit. Pat.* 687541, 1951/54. The design of a classifier for pulverizing mills is described: Baffles and auxiliary classifying air permit easy adjustment to the desired degree of fineness.

2661. **Use of Spiral Classifiers as Ball Mill Feeders.** KING, T. C. *Min. Engng. N.Y.*, 1950, 2(9), 951; *Trans. Amer. Inst. min.* (*Metall.*) *Engrs.*, **187**. A variable speed 24-in. revolving helix de-waters lead-zinc concentrate and transfers it to the ball mill scoop.

2662. **A Review of Recent Developments in the Use of Hydrocyclones in Mill Operation.** KOK, S. K. DE. *J. chem. Soc. S. Afr.*, Feb. 1956, **56** (8), 281–94. The rapid increase in the number of cyclones in use in the South African gold mining industry and their extreme flexibility have tended to produce a condition in which a study of fundamental characteristics has lagged behind practice. The need for more fundamental research is pointed out. The results of tests on rand ores with large cyclones are embodied in 9 graphical and 9 tabular presentations. 5 refs. [P]

2663. **Application of Hydrocyclones in Coal Washeries.** KRIJGSMAN, C. International Conference on Coal Preparation, Paris, 1950, Paper E.4; *Rev. Industr. min.*, 31 Mar. 1951 496–511; English Issue, No. 4, 462–77.

2664. **Trials and Performance Data with the Hydrocyclones.** KRIJGSMAN, C. *Chem.-Ing.-Tech.*, 1951, **23** (22), 540–2. [P]

2665. **Fine Grinding Investigations at Lake Shore Mines. (Pyrites and Gold.)** LAKE SHORE MINES STAFF. *Trans. Canad. Min. Inst.* (*Inst. Min. Metall.*), 1940, **43**, 299–434. On pp. 306–11 is a discussion on necessity for calibration of test sieves by sieving the material concerned, since no specific relation has been found between the sieving value of a screen (325) mesh and the dimensional features. *See* No. 1119.

2666. **Investigations into Cyclones Separation.** TER LINDEN, A. J. *TonindustrZtg*, 1953, **77**, 3/4, 49–55. A geometrical and mathematical analysis, with graphical representation of data. 4 refs.

2667. **Unsolved Problems in the Production of Chocolate.** LIPSCOMBE, A. G. *Chem. & Ind.* (*Rev.*), Nov. 1954, 1375. The Bahco (Micro Particle) classifier is described and illustrated. A table of results is given. The makers claim that complete micro-particle separation of a sample into eight grain sizes by a laboratory technician need not exceed two hours, allowing about 15 minutes per fraction. The separation is into definite grain size ranges.

2668. **The Centricyclone in Specific Metallurgical Applications.** MCGUIRE, P. G. (Oliver United Filters). *Rock Prod.*, 1953, **56** (4), 178, 182. A résumé of this paper states that the feed is accelerated by a power-driven impellor instead of by pressure at an orifice, which is absent, while the feed is not tangential. The maximum velocity at the periphery of the impellor is about 100 ft/s or 800 G.

2669. **Theory of Fine Grinding, IV.** MARTIN, G. and WATSON, W. *Trans. ceram. Soc.*, 1926, **25**, 226–9; *Brit. Abstr.*, 1927, B543. Analysis of large quantities of crushed sand. In elutriation it was confirmed that log W/x^3 plotted against x gave a straight line. W is the weight of grade and x is the average arithmetical diameter of the particles in a grade.

2670. **Pneumatic Separation of Materials.** MIAG VERTRIEBSGESELLSCHAFT, AG. *Brit. Pat.* 688335, 1949. The material is carried up pneumatically in a series of pipes, each pipe protruding into the next pipe of larger diameter, each annular base being provided with outlet for collection of the successive sizes.

2671. **Graphical Methods of Sizing Cyclone Dust Collectors.** MONROE, L. *Heat & Ventilation*, 1950, **47**, 63–6; *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1951, **15**, 2–56. A review of the work and recommendations of various authors on the dimensions of cyclone separators for given separation factors, volume of air and area ratio of cylinder to inlet. A nomogram has been developed from which the diameter of the cyclone can be taken; a table gives the relationship between this and other major dimensions of the cyclone. A further table gives the separation factor of various dusts.

2672. **The Cyclone as a Dust Separator.** NAGEL, R. *Brennst.-Wärmekr.*, 1951, **3**, 331–5; *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1951, **15** (12), 449. A higher efficiency has been obtained with two identical cyclones in series (up to 97% separation) than with a large number of the same cyclones in parallel, because of the unequal distribution in the parallel arrangement.

2673. **The Liquid-Solid Cyclone as a Classifier in a Tertiary Tube-Milling Circuit.** PEACHEY, C. G. *J. chem. Soc. S. Afr.*, Sept., 1955, **56** (3), 107–23. The investigation was put in hand in order to understand and define the limitations of the cyclone, which have to be understood before satisfactory application can be accomplished; and further to overcome those limitations. The operating variables in the feed were correlated with performance data and dimensions of the cyclone and the results are presented in

seven graphs. The conclusions indicate the measures to adopt to meet variations in feed and maintain the desired separation and performance. The optimum diameter of the cyclone for various feed conditions still remains to be determined. Apart from altering the diameter, too coarse an overflow can only be met by using secondary classification.

2674. **Dust and Mist Collection.** Perry, J. H. *Chemical Engineers Handbook*, 1013, 1950, McGraw-Hill, New York. A comprehensive bibliography, compiled by C. E. Lapple.

2675. **Air Separator Tube Mills.** Rammler, E. and Prockat, F. *Zement*, 1934, **23**. Pp. 519–525. The methods of air classifying are described and copiously illustrated. Pp. 557–561. An analysis of the results of classification of ground cement ingredients. Full tabular comparisons. Pp. 575–577. The application of air classification and pneumatic drying to tube mill products. [P]

2676. **Method of Operation and Efficiency of Air Classifiers.** Rosin, P. and Rammler, E. *Ber. Reichskohlenrates*, No. 24; *Zement*, 1929, **18**, 804, 888, 942, 969. Effects of design and product characteristics on the efficiency of classifiers, i.e. moisture, ash, specific gravity, shape of particle, superfine content, temperature and humidity of the carrying gases and type of construction. [P]

2677. **Investigation of the Method of Operating Air Classifiers.** Rosin, P. and Rammler, E. *Ber. Reichskohlenrates*, No. 24; *Zement*, 1930, **19**, 984, 1011, 1035, 1060. Experiments on a three-roll mill with Pfeiffer air classifier are reported. Data on the effects of throughput, speed and circulating rate on the working of the classifier, and variation of separating efficiency at different finenesses are presented. [P]

2678. **Development of a New Screening Process for the Separation of Granular Mixtures by Means of a Cyclone Separator.** Rumpf, H. and Wolff, K. *Mon. Bull. Brit. Coal Util. Res. Ass.*, 1949, **13** (7), 234. Obtainable in microfilm or photostat form from: Lending Library Unit, D.S.I.R. Ref. FDX492, Frames 7443–7613. Mathematical and experimental investigations into the possibility of using the cyclone for separating out any desired grain size in the range of 1–300 mu.

2679. **The Use of Classifiers in the Brick and Tile Industry.** Schouten, C. and Voskuil, J. *Klei*, 1951, **1** (12), 3. Mechanical, hydraulic and hydrocyclone types of classifiers are briefly described.

2680. **The Design and Performance of Cyclone Separators.** Stairmand, C. J. *Trans. Instn chem. Engrs, Lond.*, 1951, **29** (3), 356–83. (Summaries in *Int. chem. Engng*, Feb., 1952, 89–90, and *Chem. Tr. J.*, 18 Jan., 1952, 1933–4.) *See also Trans. Instn chem. Engrs, Lond.*, 1951, **29** (3), and Symposium on Particle Size Analysis, Institute of Chemical Engineers, 1947. *See also Engineering, Lond.*, 1949, **168**, 409, and R. A. Bagnold, *The Physics of Blown Sand*, 1949, Methuen & Co., p. 5. In the present paper, the general mechanism of the cyclone is described and fully illustrated, and performance data for some practical designs are presented. The factors affecting the efficiency of cyclones are discussed, and experimental support is given for the views expressed on design features. A recommended testing technique is included. [P]

2681. **Bibliography of the Liquid–Solid Cyclone.** Tangel, O. F. and Brison, R. J. Battelle Mem. Inst. Columbus, Ohio. Minerals Benef. Div., Feb. 1955. A bibliography of 105 references, for the separate years 1948 to 1955, including 8 refs. up to 1948. It does not pretend to be complete, since no extensive search was made. The references are not annotated.

2682. **Mechanism of the Cyclone.** Tarjan, G. (Institute of Mineral Dressing, Technical University, Sopron.) *Bányász. Kohász. Lap.*, 1950, **5**, 610–4. Abstracts from the Hungarian in *J. Iron St. Inst.*, 1951, **168**, 86. A mathematical analysis is given of the laws governing the theory of cyclones for gas cleaning.

2683. **The Hydrocyclone in Manganese Preparation.** TARJAN, G. (Institute of Mineral Dressing, Technical University, Sopron.) *Acta tech. hung.*, **4**, 135–44. (English with Russian Summary.) The losses by the normal separation method are referred to, and much improved separation by means of the hydrocyclone is described. The loss of metal was halved. 'The Theory and Use of the Hydrocyclone' is discussed in *ibid.*, 1953, **7** (3/4), 389–409. A mathematical analysis of the operation of the hydrocyclone and criticisms of previous work are presented. 7 refs.

2684. **Centrifuges, Separators of Highest Efficiency.** TRAWINSKI, H. *Chem.-Ing.-Tech.*, 1954, **26** (4), 189–201; *Glückauf.*, 1954, **90** (25/26), 704. A theoretical treatment of centrifuge separation is followed by a table of performance and design data of various industrial types of centrifuge and a classification in tabular form of 20 types of centrifuge. A brief description of the hydrocyclone is given. 32 refs. [P]

2685. **Hydrocyclones in the Dressing of Ores.** TRAWINSKI, H. *Chem.-Ing.-Tech.*, 1955, **27** (1), 13–17. The results of tests with iron ore, copper-zinc ore and lead ore by the recently applied hydrocyclone method of separation, are reported and presented in a series of six graphs embodying performance data. In *ibid.* (4), 193–4, multi-hydrocyclones of latest construction are described by the same author.

2686. **Sizing and Sorting in Centrifugal Separators.** TRAWINSKI, H. International Ore Dressing Congress, Goslar, May 1955. Gesellschaft der deutsche Metallhütten und Bergleute. The author considers that hydrocyclones have an upper limit of separation which coincides with the lower limit of practical screening: it may be possible to make cuts at 300-mu sizes by operating a cyclone in a horizontal position. If hydrocyclones are to be used for thickening (settling), it is necessary to use a first-stage classifier of larger diameter and a second stage of smaller diameter for thickening. Its advantage in a grinding circuit over static classifiers is its ability to thicken pulps. The strong shearing effects make it possible to use hydrocyclones for starch and flocculated pulps. Discussion: high, medium and low pressure cyclones were eventually considered as denoting pressure of 12 metres, 3–5 metres and 30 cm. (The latter is rather low.) Medium pressure cyclones gave worse separation for larger particles than heavy media plants. The reason for the appearance of large particles in the overflow of a cyclone was best given by Kelsall who had found at A.E.R.E. that some short circuit of some magnitude existed. The 180° cyclone now marketed in the U.S. had more erosion on the vortex finder, but less on the wall. Patching suggested this might be due to 'sanding' of the walls, as found at A.E.R.E. More research was needed on operating variables, e.g. the rate of injection and the nature of the core. Trawinski said that the latest Dorrclones had a flat spiral feed and entry over a large proportion of the circumference.

2687. **Means of Inhibiting the Escape of Oversize Particles from Circulatory Pulverizing Mills.** TROST, C. *U.S. Pat.* 2588945, 1952. A new guard ring device to prevent the escape of oversize particles from circulatory pulverizing mills.

2688. **A Study of the Application of the Cyclone Washer and its Application to Witbank Fine Coal.** VAN DER WALT, P. J. *J. chem. Soc. S. Afr.*, Aug. 1950, **51**, 2.

2689. **Fluo Solids Air Sizer and Dryer.** WALL, C. J. and ASH, W. J. *Industr. Engng Chem.* (*Industr.*), 1949, **41** (6), 1247.

2690. **Concentric Cone Separator.** WILSON, B. W. *Aust. J. appl. Sci.*, Mar. 1953. Description of the turbocyclone for separation of particles well below 10 mu. Two concentric rotating cones contain the gas in the annulus. The gas is accelerated to the same angular velocity by a series of carefully designed blades. At the discharge end the gases pass through another set of blades, and so some of the rotational energy is recovered. The particles or droplets migrate towards the outer casing where a film of liquid prevents re-entrainment and carries away the particles. A number of snags has still to be overcome.

Dust and Fire Hazards

GENERAL PAPERS

2691. **Dust Proof Sifting Machine.** ANON. *Engineering, Lond.*, 1952, **174**, 647. The machine contains eight sieves with a total capacity up to 3 tons per hour. It is totally enclosed, but an exhaust fan can be fitted if desired.

2692. **Air Filters for Ventilating and Air Conditioning Installations.** ANON. *Sulzer tech. Rev.*, 1955 (2), 1–15. Describes the significance of dust particles in the air, the contents at various localities and the appropriate dust limits for industrial, medical and other operations.

The methods of measuring atmospheric dust (9 methods) are described, the apparatus illustrated and the capabilities tabulated. The ranges of application to numerous industrial dusts are presented graphically.

2693. **Dust Separation in the Chemical Industry.** ANON. *Edg. Allen News*, 1955, **34** (401), 241–4. Centrifugal separators and collectors are described.

2694. **Filters for Air Supply to I.C. Engines.** *British Standard* 1701 : 1950. An appendix includes a specification for the test dust to be used, and the methods of verifying that the dust is in accordance with the requirements.

2695. **Review of the Literature on Dusts.** ANON. *Bull. U.S. Bur. Min.*, No. 478, 1950, 333 pp.

2696. **Anniversary of the Working Committee on Dust Technique. Essen, March 1953.** *TonindustrZtg*, May 1953, **77**, 9/10, 176–80. Full summaries of a dozen contributions are given.

2697. **Dust Prevention and Suppression.** Min. Fuel and Power, Safety in Mines Estab. 1955, H.M. Stationery Office. 13 pp.

2698. **Dust Forming Capabilities of Materials.** ANDREASEN, A. H. M. and RUSMUSSEN, N. H. *Kolloidzschr.*, 1939, **86** (1), 70–7.

2699. **Characteristics and Choice of Apparatus for Dust Removal.** ANSELM, W. *Zement-Kalk-Gips.*, 1950, **3** (8), 165–76; *Chim. et Industr.*, 1951, **65** (1), 61. Factors influencing the choice of cyclones for several processes, including carbon black manufacture.

2700. **Dust Removal, Grinding Technique, Vertical and Rotary Kilns.** ANSELM, W. 1952. Instituto Tecnico de la Construcion y del Cemonto, Madrid. A long abstract, in German, in *Zement-Kalk-Gips.*, 1953, **6** (4), 131.

2701. **Control and Recovery of Dust and Fume in Industry.** ASHMAN, R. *Chem. Tr. J.*, 1952, 1221–4; *Proc. Instn mech. Engrs, Lond.*, 1952, **1B** (5), 157–68, Discussion 175–9. The purposes of control and recovery. Nature of dusts and fumes. Methods of control and separation systems. Protection from explosions and fires. Suggested standardization of design. Dispersoid paths of particles through fabrics, the dust particles being caught on the protruding fibres of the cloth rather than on the apertures in the weave. Numerous diagrams. 10 refs.

2702. **Dusts.** BRISCOE, H. V. A. Royal Institute of Chemistry Meeting, Slough, Jan. 1949. The lecture dealt with the general aspects of dusts in relation to health, their quantities, sizes, nature and specific effects. The liberation of alkali from dusts and probable effect on the lung were discussed, other chemical aspects and effects were also mentioned, and the use of aluminium powder to counteract silicosis referred to. The author's own work on the effect of dusts on weevils was described, and how

dusts can be classified into sharp and soft by their effect on the wax protective coating on the weevil. If this is scratched the weevil will die from loss of moisture. If the content drops from 40% to 30% they die.

Wet ground material was found to be more potent than dry ground. The explanation is that in wet grinding the particles are kept separate. They aggregate when dry ground.

2703. **A Review of the Present Methods of Testing Industrial Dusts for Inflammability.** Brown, K. C. *Min. Fuel and Power, Safety in Mines Estab., Res. Rep.*, No. 21, 1951, H.M. Stationery Office. 15 pp.

2704. **Dust Explosions in Factories. Closed Circuit Test Apparatus.** Brown, K. C. and Woodhead, D. W. *Min. Fuel and Power, Safety in Mines Estab., Res. Rep.*, No. 86. 1953, H.M. Stationery Office. 17 pp.

2705. **Generation and Tyndallmetric Measurement of Dust Clouds.** Chen, W. L., Foresti, Jr., R. J. and Charmbury, H. B. *Industr. Engng Chem.* (*Industr.*), 1952, **44** (5), 1171–4. Dust of 1–30 microns; cloud produced by a sonic generator, which can be varied to the dust concentration required. 22 refs.

2706. **Physico-Chemical Studies on Dust. Pts 1 and 2.** Clelland, D. W., Cumming, W. M. and Ritchie, P. D. *J. appl. Chem.*, 1952, **2** (1), 31–41. *See under* Theory, Surface Phenomena.

2707. **Physico-Chemical Studies on Dusts. Pt 3. Factors Affecting the Wetting of Airborne Silica Dusts by Aqueous Sprays.** Cumming, W. M., Massie, W. H. S. and Ritchie, P. D. *J. appl. Chem.*, 1952, **2** (7), 413–22. 21 refs.

2708. **Physico-Chemical Studies on Dusts. Pt 4. Accuracy of Chemical Estimation of Free Silica in Rocks and Mineral Dusts.** Cumming, W. M., Dempster, P. B. and Ritchie, P. D. *J. appl. Chem.*, 1952, **2**, 658–63. 11 refs. For Parts 1 and 2, *see under* Clelland, above.

2709. **Determination of Minimum Air Velocities for Exhaust Systems.** Dallavalle, J. M. *Heat Pip. Air Condit.*, 1932, **4**, 639–41.

2710. **Control of Industrial Dusts.** Dallavalle, J. M. *Mech. Engng, N.Y.*, 1933, **55**, 621–4.

2711. **The Importance of Velocity Characteristics in the Design of Local Exhaust Hoods.** Dallavalle, J. M. *J. Industr. Hyg.*, 1938, **15**, 18–26.

2712. **(A) Principles of Hood Design. (B) The Significance of Dust Counts.** Dallavalle,, J. M. *Publ. Hlth Rep., Wash.*, No. 54, 1939, 1095–1104.

2713. **Dust Collector Costs.** Dallavalle, J. M. *Chem. Engng*, 1953, **60** (11), 177–84. Exclusive comprehensive cost data are described and also presented in a series of 14 curves for various methods of collection. A short note on sonic collectors is included. Illustrations.

2714. **Dust and Mist: Inhalation Risk and Particle Size.** Davies, C. N. *Brit. J. industr. Med.*, 1949, **6**, 245–53. Respiratory absorption and elimination are reviewed and the site of action is discussed. It is shown that particle size is decisive in governing the region of initial deposition in the respiratory tract and experiments are cited. Previous studies on the penetration of airborne clouds through the nose showed that 80% penetration occurs for particles of radius 0·9 mu, 50% at 2 mu and 20% at 6 mu.

2715. **The Separation of Airborne Dust and Particles.** Davies, C. N. *Proc.* (*B*) *Instn mech. Engrs, Lond.*, 1952, **1B**, 185–98. A study of the physical theory, underlying various methods of separating particles from gases, leading to development of formulae of value to those concerned with the design and engineering of separators. New theories of elutriators, cyclones, and of fibrous filtration are put forward, with

graphs and tables which enable them to be applied without difficulty to practical problems. 29 refs. Discussion and communications 199–213. 50 refs.

2716. **Dust is Dangerous.** DAVIES, C. N. 1954, Faber, 116 pp., 21*s*. 0*d*. The book deals with industrial dust hazards, sampling, explosions, house and non-industrial dusts and radioactive dust. The effects on health are stressed.

2717. **Notes on the Physics of Dust Dispersion.** DAWES, J. G. *Min. of Fuel and Power Safety in Mines Estab. Res. Rep.*, No. 3, 1950, H.M. Stationery Office. 37 pp.

2718. **Industrial Dust.** DRINKER, P. and HATCH, T. 1954, McGraw-Hill, London. 401 pp.

2719. **Stofontploffingen. (Dust Explosions.)** DUSSEN, A. A. Van der. 1933, N. V. Drukkerei, Korteweg, Rotterdam.

2720. **Review of Papers Presented at the Autumn 1954 and Spring 1955 Meetings of the Fachausschuss für Staubtechnik. V.D.I.** EICHHORN, J. L. *Kolloidzschr.*, 1955, **42** (1), 50–2. Papers reviewed are: Control of sizes shape during precipitation, D. Laufhutte; The Banco centrifugal classifier, H. van der Kolk; The micro decanting machine of Buhler Gessner, W. Jutzi; Optical particle size analysis, H. E. Rose; Precipitation of dusts by means of their electrical properties, A. Winkel.

2721. **Dust Technique.** FEIFEL, E. *Radex Rdsch.*, 1952–4. *See under* Size Distribution.

2722. **Foam Screen Licks a Dust Control Poser.** FOULON, L. H. A. *U.S. Pat.* 2672209, 1954. *Chem. Engng*, 1954, **61** (7), 278. A layer of foam is used to catch very fine dust particles defying other means of collection. Foam has a high wetting power and good stability.

2723. **Dust and Its Effect on the Respiratory System.** GILL, G. H. 1947, H. K. Lewis & Co., Ltd., London.

2724. **The Size Frequency of Particles in Mineral Dusts.** GREEN, H. L. *Trans. Faraday Soc.*, 1936, **32** (8), 1091–1100.

2725. **Investigations on the Suitability of Various Dust Measuring Instruments for the Industrial Measurement of Mineral Dusts.** HASENCLEVER, D. *Staub*, 15 Sept. 1955 (41), 388–435. A detailed account describing special test plant for survey of measuring instruments, and statistical basis for investigation. The following instruments were investigated: Tyndalloscope (built 1952), balance after Gast, filter instrument after Marthius, newly developed Conimeter HS, and thermal precipitator. All these instruments are compared in detail. 24 illustrations, 12 tables, 35 refs.

2726. **Filter Efficiency and Standardization of Test Dust.** HEYWOOD, H. *Proc. Instn mech. Engrs, Lond.*, 1952, **1B** (5), 169–74; Discussion, 175–9. Basic theory for efficiency of aircleaners and filters is developed. Mass efficiency and intrinsic efficiency. The latter is independent of size composition of the dust, and is expressed as collection efficiency for individual particle sizes.

Description of research which has led to the formulation of a standardized test dust for cleaners and filters for air supply to internal-combustion engines B.S. 1701: 1950 has been adopted by Ministry of Supply. The object of the specification is to ensure the presence in the test dust of all sizes likely to be encountered and a uniform grading of size. 5 refs.

2727. **Aerodynamic Properties of Screens and Fabrics.** HOENER, S. F. *Textile Res. (J.)*, April 1952, 274–80. Statistical analysis of experimental data. The conventional method of measuring and quoting the permeability of fabrics is without much satisfying foundation. The pressure loss coefficient (equation given) seems to be a better measure and the reverse of the equation could be used as a non-dimensional parameter indicating the permeability of fabrics and other material. 12 refs.

2728. **The Hollinger Crushing Plant.** HOLLINGER MILL STAFF. *Canad. Min. metall. Bull.*, 9/1953, **46** (499), 550–76. Pages 571–3 describe the measures taken to control dust, both underground and at the surface crushing plant. Cyclone, fan and dust concentration data are tabulated.

2729. **The Study of Dusts in Industrial Atmospheres.** HOLT, P. F. *Metallurgia, Manchr*, 1951, **43**, **44**. Pt I. Determination of the particle count. Pt II. The Konimeter and jet sampling instruments. Pt III. The impinger and cascade impactor. Pt IV. Determination of mass concentration. Pt V. Determination of mass concentration by the volatile filter method.

2730. **New Experiences in the Field of Sonic Dust Extraction.** (Summaries in French and English.) JAHN, R. *Radex Rdsch.*, 1955, (7), 625–31. Basic principles of sonic and ultrasonic dust extraction are described and compared. The superiority of sonic extraction is emphasized. 7 illustrations.

2731. **Principles of Present Day Dust Collectors and their Application to Mining and Metallurgical Industries.** KANE, J. M. and WALPOLE, R. H. *Min. Engng, N.Y.*, 1953, **5** (1); *Trans. Amer. Inst. min. (metall.) Engrs*, 1953, **196**, 85–8.

2732. **Crushing Plant Dust Control at the Roy Mines Division. Kennecott Copper Corporation.** KNEEDSON, J. F. *Min. Engng, N.Y.*, 1953, **5** (7); *Trans. Amer. Inst. min. (metall.) Engrs*, 1953, **196**, 689–95. Description, illustrations and data on the exhaust system of the above mines. 6 refs. Specifications for hood, face velocities and branch velocities are given.

2733. **Practical Aspects of Industrial Dust Suppression.** LAWRIE, W. B. *Brit. J. industr. Safety*, 1951, **2**, 75–83; *Rubber Abstr.*, 1952, **30** (4), 163. Elimination, control, ventilation, recent developments, diagram of removal system. 4 refs.

2734. **Aerosol Indicator for Rapid Testing of the Dust Content of Air.** LUNGGREN, G. and WILNER, T. *Engng Dig., Los Angeles*, 1950, **11**, 309–10; *Tekn. Tidskr., Stockh.*, 1950, **80**, 551–2. Operates in a manner similar to the ultramicroscope for particles down to 0·5 mu.

2735. **Atmospheric Pollution.** MCCABE, L. C. *Industr. Engng Chem. (Industr.)*, 1953, **45** (11), 109A. Efficiencies of various dust control equipment for various particle sizes are presented in ten curves.

2736. **Handbuch der Staub Technik.** MELDAU, R. 1952, Deutscher Ingenieur Verlag, Düsseldorf. Pt 1. 204 pp., 155 illustrations, 647 refs. Fundamental theory of dust formation and characteristics. Pt 2. 253 pp., 349 illustrations, 500 refs. Dust technology. The formation of dusts, their elimination or collection and problems connected with dusts. A long summary of this work is given in German in *Zement-Kalk-Gips.*, 1953, **42** (4), pp. 131–2.

2737. **Pressure Relieving Capacities of Diaphragms and Other Devices for Venting Dust Explosions.** NAGY, J., ZEILINGER, J. E. and HARTMANN, I. *Rep. Invest. U.S. Bur. Min.*, No. 4636, 1950.

2738. **Control of Dusts by Water Mists.** NELSON, K. W. *Arch. industr. Hyg.*, 1951, **4** (1), 25–31. Mists are applied in crushing operations from pneumatic atomizing nozzles having the advantage of low costs and simple installation, while the crushed material is surface moistened and thus less dusty in later handling. Applications are suggested including reduction of pneumoconiosis-producing dusts.

2739. **Protecting Men and Machines from Dust.** NEMMERS, R. J. *Compr. Air (Mag.)*, 1954, **59** (9), 242–7; (10), 280–4. A Survey Article; 21 illustrations.

2740. **Sonic Precipitation of Smoke, Fumes and Dust Particles.** NORD, M. *Chem. Engng*, 1950, **57** (10), 116–9. A brief outline of the theory, and a review of the most important patents and papers published on the subject.

2741. **Agglomeration of Smoke, Fog, or Dust Particles by Sonic Waves.** St. CLAIR, H. W. *Industr. Engng Chem.* (*Industr.*), 1949, **41** (11), 2434–8.

2742. **Dust Flames and Dust Explosions.** SCHLAFFER, P. *Monatsbull. schweiz. Ver. Gas- u. Wasserfachm.*, 1951, **31** (3), 69–82.

2743. **Industrial Hygiene.** SHRENK, H. H. *Industr. Engng Chem.* (*Industr.*), 1953, **45** (8), 111A–112A. Current research on the effects of dusts is increasing, but additional basic studies are needed. The retention of dust in the alveolar tract decreases with decrease in particle size. The weight and surface area of dust are related to its effects. Some detailed experimental results are included in this review and the work of E. J. King. *Brit. J. industr. Med.*, 1953, **10**, 76, is quoted.

2744. **New Dust Filters Giving Unequalled Results.** SMITH, W. J. and STAFFORD, E. *Chem. Engng*, 1950, **57** (8), 105. A new filter, based on specially-treated paper, pulp and asbestos, has been developed. The filter paper has high efficiency in a thin sheet, and under average conditions has a long life.

2745. **The Sampling of Dust-laden Gases.** STAIRMAND, C. J. *Trans. Instn chem. Engrs, Lond.*, 1951, **29**, 15–44. The principles of sampling dust-laden gases are set forth, the methods are described and apparatus illustrated. Performance data for the filters are summarized in a series of tables. A standard portable sampling apparatus and a self-compensating electrostatic sampler are described. Attention is given to the problem of flow rate at elevated temperature where water vapour is present or where the composition is different from the calibrating conditions. 8 refs.

2746. **The Fundamental Mechanism of Dust Collection.** STAIRMAND, C. J. *Heat, Vent. Engr.*, 1953, **25**, 207.

2747. **Investigation of a Photo-electric Device for the Determination of Low Concentrations of Dust.** STONE, D. E. *Rep. Invest. U.S. Bur. Min.*, No. 4782, 1951, 6 pp., 6 figs.

2748. **The Presentation and Meaning of Grain Size Distribution.** STRASSEN, H. *Radex Rdsch.*, 1955 (1), 345–8. Contribution to the paper of E. Feifel, *Radex Rdsch.*, 1954, 7/8, 239–55. The paper by Feifel concerns silicosis and dust research and the attempt to follow the important size problem into the range beyond measurable limits.

The present author discusses the anomalous results, where the residues *R* in the distribution function differ according to whether the sieve range is based on an arithmetical or geometrical scale.

2749. **Dust Characteristics, Problems and Control.** Sturtevant Engineering Co., London. Publication No. 2004, 1956, 71 pp. This book is copiously illustrated and deals with dust sizing, atmospheric pollution, dust hazard in industry, and characteristics of dust filters and separators. The treatment is in the nature of a text-book.

2750. **Industrial Dust.** VOWLES, H. P. *J. India Soc. Engrs*, May 1948, **13**, 92–3. The effect on lung damage of stone dusting in coal mines is discussed. The effectiveness of limestone containing a high proportion of magnesium carbonate on reducing explosion hazards depends on its dispersibility, which increases with particles below 10 mu. Particles above 10–12 mu seldom find their way into the lungs, and recent research indicates that the lower limit of particle size associated with lung damage is about 1 mu.

2751. **Silica Dusts: Foundries and the Factories Act, 1937.** WEBLEY, L. *Found. Tr. J.*, 1955, **99** (2043), 479. A barrister's survey of employers' liabilities in respect of precaution against injurious dust.

2752. **The Danger of Dust.** WEBSTER, A. *Chem. Age, Lond.*, 20 Aug. 1955, **73** (1884), 373–7. The health and safety risks of dust and the methods designed to avoid these risks are reviewed. Quotations are made from the 'Fire Protection Association Technical Booklet No. 5' concerning causes of fires and materials providing risks. Such aspects as air recirculation, turbulent flow, cleanliness, pressure peaks and relief, poisonous and explosive effects are discussed.

2753. **Dedusting during Handling of Dry Materials.** WITTENBURG, D. *Chim. et Industr.*, 1951, **66** (7), 56–61. Dust is spread by air currents in various operations quoted. Examples and data are given for dust removal installations.

2754. **Dust and Health in Industry.** WRIGHT, B. M. *Advanc. Sci., Lond.*, 1956, **12** (48), 411–8. A discussion held at the British Association Meeting at Bristol, Sept. 1, 1955. 15 refs.

FIRE HAZARDS

2755. **Charging of Agitated Liquids in Ball Mills.** ANON., *Farbe u. Lack*, 1948, **54** (12), 313–4; 1949, **55** (2), 34. The accumulating of electrostatic charges can be prevented by adding a polar material such as alcohol or a soap, and earthing the mill with a sliding contact.

2756. **Report on Experiments into the Means of Preventing the Spread of Explosions of Carbonaceous Dust.** Home Office, London. 1935, H.M. Stationery Office. 12 pp., 6 figs.

2757. **Report for 1955.** Chief Inspector of Factories. Cmd 8. H.M. Stationery Office, 9*s.* 0*d.* Emphasis occurring in a cyclone or in the grinding mill before reaching the cyclone, and of how serious fires can occur when the bottom of the cyclone is open instead of being provided with an isolating device such as a rotary valve or screw conveyor. Methods of isolation and other precautions are described.

2758. **Preventing and Minimizing the Effects of Dust Explosions in Manufacturing Plants.** Factory Insurance Association Special Hazard Study, No. 5. Hartford, Conn., 1940.

2759. **Model Code of Safety Regulations for Industrial Establishments for the Guidance of Governments and Industry.** International Labour Office, Geneva, 1949.

2760. **Fire Hazards in the Plastics Industry.** *Chem. Age, Lond.*, 11 Nov. 1950, **63** (1635), 675.

2761. **Static Electricity.** U.S. National Fire Protection Ass., Boston, Mass., Pamphlet, 1950, 51 pp. This pamphlet is included in *National Fire Codes*, Vol. 2, Combustible solids, dusts, chemicals and explosives, 1954.

2762. **Eliminating Static Electricity by Radioactivity.** *Atomics*, Mar. 1951, **2** (2), 71–6. Previous static eliminating devices have not been found fully satisfactory. The employment of radioactive sources would seem to be the best solution for many industrial materials, e.g. paper, fabrics, etc. Equipment is described and illustrated. Applications are described and some limitations are itemized.

2763. **Industrial Standards.** *Chem. Engng News*, 1951, **29** (6), 502. The U.S. National Fire Protection Association, Dust Explosions Hazards Committee, has prepared 17 codes of standards required for different industries. *See also Handbook of the Fire Protection Association, U.S.A.* 1954, 96 pp.

2764. **Dust Explosions in Industry.** *O.E.E.C. Technical Assistance Mission.* No. 67, 1952. H.M. Stationery Office. Two recommendations are made: (1) concerns standard methods of testing; (2) internationally recognized standardized apparatus. Summary in *Chem. Age, Lond.*, 26 Dec. 1953, 1521–3.

2765. **Safety Provisions for Industrial Plants Against Combustible Dusts.** *Staub.*, 15 Sept. 1953 (33), 243–66; *Fuel Abstr.*, 1954, **15** (1), 189.

2766. **Dust Explosions and Precautions.** Report 1954. Chief Inspector of Factories. Cmd. 9605. H.M. Stationery Office. 8*s.* 0*d.* net. Examples of accidents and prevention are abstracted in *Chem. Tr. J.*, 16 Dec. 1955, 1637–8.

2767. **Lists of Dusts, Classified as regards Inflammability and Capacity for Transmit-**

ting Explosions. Min. Lab. and Nat. Service, Factory Dept., Form 894, 1947, H.M. Stationery Office.

2768. **Notes on the Installation of Plant for the Grinding of Flammable Materials.** Min. Lab. and Nat. Service, Factory Dept., Form 896, 1950, H.M. Stationery Office. 4 pp., 2 figs.

2769. **Prevention and Propagation of Flame in Aluminium Dust Explosions.** Min. Lab. and Nat. Service, Factory Dept., 1951, H.M. Stationery Office. 16 pp.

2770. **Flammability of Dusts.** Min. Lab. and Nat. Service, Factory Dept., Form No. 830, 1953, H.M. Stationery Office. A large range of dusts has been examined and classified according to relative explosion hazard.

2771. **Report of Research and Technologic Work on Explosives, Explosions and Flames, for the Fiscal Years 1946 onwards.** *Rep. Invest. U.S. Bur. Min.*, Nos. 4176 and 4502.

2772. **Industrial Fires and Explosions from Electrostatic Action.** BEACH, R. *Mech. Engng, N.Y.*, 1953, **75** (4), 307–13. 14 refs.

2773. **Explosions in Coal Pulverizing Mills.** BECHDOLDT, H. *Mitteilungen der Vereinigung der Grosskesselbesitzer*, 2 July 1954 (29), 172–4.

2774. **Self-Promoted Dust Explosions.** BLACKTON, S. C. *Chem. Age, Lond.*, 18 July 1942, **47** (1203), 53.

2775. **The Inflammability in Suspension of Mixtures of Combustible and Incombustible Dusts.** BOWES, P. G., BURGOYNE, J. H. and RASBASH, D. J. *J. Soc. chem. Ind. Lond.*, 1948, **67**, 125–30.

2776. **The Electrostatic Ignitability of Dust Clouds and Powders.** BOYLE, A. R. and LLEWELLYN, F. J. *J. Soc. chem. Ind., Lond.*, June 1950, **69** (6), 173–81.

2777. **The Value of an Inert Gas as a Preventive of Dust Explosions in Grinding Equipment.** BROWN, H. R. *Tech. Bull. U.S. Dep. Agric.*, No. 74, 1928.

2778. **Dust Explosions Hazards in Plants Producing or Handling Aluminium, Magnesium or Zinc Powder.** BROWN, H. R. *Inform. Circ. U.S. Bur. Min.*, No. 7148, Mar. 1941.

2779. **Inflammability and Explosibility of Metal Powders.** BROWN, H. R. *Rep. Invest. U.S. Bur. Min.*, No. 3722, 1943.

2780. **Prevention of Gas and Dust Explosions.** BROWN, H. R. *Inform. Circ. U.S. Bur. Min.*, No. 7309, 1946, 7 pp. A collection of data on industrial dust explosions. Coal, wood, metals and plastic dust explosions are considered. Test data on carbonaceous dusts are given.

2781. **Design of Explosion Pressure Vents.** BROWN, H. R. *Engng News Rec.*, 3 Oct. 1946, 445–7.

2782. **Summary of Large-scale Dust Explosion Work carried out by the Factory Department.** BROWN, K. C. Min. Lab. and Nat. Service, Factory Dept., F.D.3. 1950, H.M. Stationery Office.

2783. **The Prevention of the Propagation of Flame in Aluminium Dust Explosions.** BROWN, K. C. Min. Lab. and Nat. Service, Factory Dept., 1950. H.M. Stationery Office. 14 pp., 10 figs.

2784. **A Review of the Present Methods of Testing Industrial Dust for Flammability.** BROWN, K. C. *Min. Lab. and Nat. Service, Factory Dept., and Min. Fuel and Power, Safety in Mines Estab. Res. Rep.*, No. 21, 1951. H.M. Stationery Office. 15 pp., 2 figs.

2785. **Dust Explosions in Industry.** BROWN, K. C. Min. Lab. and Nat. Service, Factory Dept., 1951. H.M. Stationery Office. 2 pp.

2786. **The Ignition of Dust Clouds by Electrostatic Discharge,** pp. 113–21. Cox, E. G. and Peace, A. G. Society of the Chemical Industry. Conference on Dust in Industry, Leeds. Sept. 1948.

2787. **The Explosibility of Very Fine Coal Dust.** Cybulski, W. *Rev. Industr. min.*, April 1953, **34** (592), 326–33. A study of the relation between explosibility and the specific surface area of very fine coal dusts. It is shown that for normal fineness (25–85% less than 75 microns), explosibility increases with specific surface, and it is possible for an extremely fine powder (even with an inert content of over 70%) to propagate an explosion. These results are from gallery experience, but they oppose certain laboratory results, where it is found that explosibility decreases with increasing fineness above a specific value. Tables, curves.

2788. **Mill Drying of Coal.** Fitze, M. E. *Trans. Amer. Soc. mech. Engrs*, May 1954, **63**, 273–6. Is shown among other advantages to reduce fire and explosion hazards.

2789. **Elimination of Static Hazards by the Use of Radioactive Strontium.** Fowlie, G. G. and Morris, G. *Industr. Chem. Mfr.*, Dec. 1953, **29**, 347, 585–90. Estimation of activity required and other aspects. The drying of lead styphnate is used as an example.

2790. **Handbook of Industrial Hazards from Explosive Dusts.** Geck, W. H. *F.I.A.T. Final Report*, No. 1169, Vols. 1 and 2, 1948. H.M. Stationery Office.

2791. **Ignition Hazards of Sugar Dust.** Geck, W. H. *Zucker*, 15 Jan. 1951, **4** (2), 31–6.

2792. **Explosive Industrial Dusts.** Geck, W. H. *Z. Ver. dtsch. Ing.*, 1 April 1953, **95** (10), 290–2. The production of explosive dusts, size limits and the incidence of fires and explosions are described. The relative frequency of occurrences for 19 materials 1927–1938 are given.

2793. **Flammable Explosive Dusts.** Geck, W. H. 1955, Deutsche Ingenieur Verlag, Düsseldorf, 232 pp. DM26.

2794. **Explosibility of Semi-Anthracite Low Volatile Bituminous Coal and Medium Volatile Bituminous Coal Dusts.** Greenwald, H. P. *Rep. Invest. U.S. Bur. Min.*, No. 3489, 1940.

2795. **Characteristics of Fuel Pitches and their Explosibility in Pulverized Form.** Hartmann, I., Howarth, H. C. and Greenwald, H. P. 1940, *Tech. Pap. Bur. Min., Wash.*, No. 617, 1940.

2796. **Effect of Relief Vents on Reduction of Pressures Developed by Dust Explosions.** Hartmann, I. and Nagy, J. *Rep. Invest. U.S. Bur. Min.*, No. 3924, 1946.

2797. **Recent Research on the Explosibility of Dust Dispersions.** Hartmann, I. *Industr. Engng Chem. (Industr.)*, 1948, **40**, 752.

2798. **Report on Research and Technological Work on Explosives, Explosions and Flames: Fiscal Years 1949, 1950.** Lewis, B. *Rep. Invest. U.S. Bur. Min.*, Nos. 4667, 1950, 68 pp.; and 4793, 1951, 67 pp. Includes accounts of investigations on dust explosions.

2799. **Fire and Explosion Hazards. Pt 2.** Long, R. *Chem. Age, Lond.*, 1954, **52** (1812), 785–8.

2800. **The Static Electrification of Dust Clouds.** Miller, J. G., Heinemann, H. and McCarter, W. S. W. *Science*, 1948, **107**, 144–6.

2801. **Fine Grinding in Tube Mills.** Pearson, B. M. *Rock Prod.*, 1952, **55** (12), 106. The conditions for fine grinding are described, and certain difficult features are discussed. Fine grinding may involve aggregation on the ball media whose effectiveness is reduced. The fine particles can thus become electrically charged and a source of sparks and fire. The danger can be avoided by earthing the mill, adding water to humidify the charge and the air in the mill (say 1% of the charge), a cold air circulation

at heated locations, addition of carbon or rosin, increase the conductivity of the air by Röntgen or by U.V. rays, or electromagnetically.

In the fine grinding of cement containing gypsum, the latter, being softer, reduces first but then aggregates, leaving the cement particles free and so reduces the delayed setting effect. The addition of raw gypsum can release considerable water, however, and so reduce electric charging.

2802. **Fires Involving Dusts.** RASBASH, D. J. Fire Offices Committee, London. Fire Protection Association Technical Booklet No. 5, 1949.

2803. **Dust Fires.** RASBASH, D. J. *Industr. Heat. Engr*, 1951, **13** (69), 195–7; (70), 230–3; (71), 278–82. A series of papers dealing with causes and prevention of dust fires in industry, explosions, settled dusts, hidden smouldering, sources of ignition and their elimination, and precautions.

2804. **Fire and Explosion Risks Due to Static Electricity.** SMART, R. C. *Prot. Civile*, Aug./Sept. 1954 (12), 30–3.

SPECIFIC MATERIALS

2805. **Sulphur Grinding.** ANON., *Chem. & Process Engng*, 1952, **33** (6), 323. *See under* Sulphur.

2806. **Magnesium: Grinding Precautions.** ANON. *Light Metal Age*, Feb. 1954, **12**, 18–19. Grinding magnesium itself does not produce sparks. Wheels and belts should never be used with spark-producing materials. Five safety rules are given, and illustrations are given of the two methods of trapping dust and exhausting dust not trapped by the liquid spray.

2807. **Dust Explosions in Industry with Particular Reference to Cereals. 1935–1942.** *Sci. Libr. Bibliogr. Ser.* No. 400.

2808. **Protecting Flour from Fire.** *Sentinel*, 1948, **4** (11), 4–5.

2809. **Dust Explosions in Mills and Grain Silos.** *Getreide*, Aug. 1950, **4** (15–16), 178–80.

2810. **Aluminium Fires.** *F.P.A.J.*, 11 Oct. 1950; *Chem. Tr. J.*, 1951, 128, 99. Details are given of an explosion at an aluminium plant in 1950 while aluminium was being milled with carbon tetrachloride.

Aluminium powder may react violently with chlorinated hydrocarbons. Details of tests are given.

2811. **Dust Explosions. Flour and Starch.** *Food Tech. in Australia*, 1951, **3** (3), 72.

2812. **Regulations for the Installation of Blower and Exhaust Systems for Dust and Vapour Removal.** Oct. 1937, U.S. Nat. Board of Fire Underwriters, New York and Chicago. Pamphlet No. 91.

2813. **Standard for the Prevention of Dust Explosions in Flour and Feed Mills.** 1952, U.S. Nat. Board of Fire Underwriters, New York and Chicago. Pamphlet No. 61C. 18 pp.

2814. **Standard for Sweeping Compounds.** January 1953, U.S. Nat. Board of Fire Underwriters, New York and Chicago. Subject No. 41. 13 pp.

2815. **Serious Sulphur Dust Explosion in Sulphur Mill. Preventive Measures.** BASSELMANN. *Chem. Abstr.*, 1941, **35** (14), 4953.

2816. **Explosibility of Agricultural and Other Dusts as Indicated by Maximum Pressure and Rates of Pressure Rise.** EDWARDS, P. W. and LEINBACH, L. R. *Tech. Bull. U.S. Dep. Agric.*, No. 490, 1935.

2817. **Prevention of Dust Explosions in Grain Milling Machinery.** (Letter to Editor.) ENRIGHT, J. C. *Fire Prot.*, April 1948, **11** (90), 148–9.

2818. **Measurement of Pressure Changes in Aluminium Dust Explosions.** GLUWITZKY, W. *Z. Ver. dtsch. Ing.*, Jan./June 1936, **86**, 687.

2819. **Inflammability and Explosibility of Metal Powders.** HARTMANN, I., NAGY, J. and BROWN, N. R. *Rep. Invest. U.S. Bur. Min.*, No. 3722, 1943.

2820. **Inflammability and Explosibility of Powders Used in the Plastics Industry.** HARTMANN, I. and NAGY, J. *Rep. Invest. U.S. Bur. Min.*, No. 3751, 1944, 38 pp. Results of a detailed investigation on 57 varieties of powders. The types of apparatus are illustrated and the results are summarized in 12 tables and 11 graphs.

2821. **The Explosibility of Starch Dust.** HARTMANN, I. and NAGY, J. *Chem. Engng News*, July 1949, **27** (29), 2071–2.

2822. **Dust Explosions During the Grinding of Synthetic Resins.** KEICHER. *Arbeitschutz*, 1943, 234.

2823. **Ventilation, Fume and Dust Control in the Paint Industry.** KLEISSLER, A. J. *Off. Dig. Fed. Paint Varn. Prod. Cl.*, No. 301, 1950, 133–5. Most dust is usually generated at the mixer. Precautions, etc., are described for both dust and solvents.

2824. **Preventing and Extinguishing Magnesium Fires.** KNIGHT, H. A. *Metals & Alloys*, 1943, **17** (5), 960–6.

2825. **Spontaneous Combustion of Metal Powders.** KOPELMAN, B. and COMPTON, V. B. *Metal Progr.*, 1953 (2), 77–9. Describes the pyrophoric properties of metal powders and methods of preventing or modifying fire risk.

2826. **Determination of Dust Concentration in Flour Mill Suction Systems.** MACKENZIE, J. M. Paper No. 51, F29, to American Institute of Mechanical Engineers. 8 pp. An abstract of the paper appeared in *Mech. Engng, N.Y.*, 1951, 73, 931.

2827. **Explosive Properties of Sugar Dusts.** MEEK, R. L. and DALLAVALLE, J. M. *Industr. Engng Chem.* (*Industr.*), 1954, **46** (4), 763–6.

2828. **Dust Problems in Flour Mills.** NAGEL, R. *Z. Ver. dtsch. Ing.*, 1 April 1953, **95** (10), 297–303. Dust problems from the earliest stone mills to modern mills are described and methods of removal are illustrated. Pressure losses and performance of cyclones are presented graphically and application to fine dust removal described. 11 refs.

2829. **Causes and Prevention of Explosions of Grain and Flour Dust.** SAUERTEIG, H. *Brandschutz*, 1952, **6** (4), 82–5.

2830. **Rules for the Operation of Powder Mills.** WEGNER, A. *Zucker*, 1953, **6**, 418–20. The operation of sugar mills and precautions against explosions, under thirteen headings, are discussed. Revised regulations are given.

2831. **Dust Explosions in Factories.** WILKES, S. H. *Trans. Instn chem. Engrs, Lond.*, 1948, **26**, 77–80; *Quart. Instn Fire Engrs, Edinb.*, 1952, **12** (5), 1/3, 62–73. All mills dealing with organic materials are liable to develop the necessary concentration for explosion. For instance, a flour mill of 50 cubic feet capacity would require only 1 oz of powdered flour to give the critical minimum of 0·02 oz/cu. ft to cause an explosion. Preventive measures are described.

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SUBJECT INDEX

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